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ILIR '01: SSC San Diego In-House Laboratory Independent Research 2001 Annual Report

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ADMINISTRATIVE INFORMATION

The work detailed in this report was carried out at SSC San Diego during FY 01 and was supported by the In-house Laboratory Independent Research (ILIR) Program administered by ONR. The ILIR program supports basic research at Navy Warfare Centers with the goal of encouraging Navy scientists and engineers to pursue innovative, high-risk, high-payoff research projects that will contribute to achieving the Warfare Centers' Missions.

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CONTENTS

INTRODUCTION

INTRODUCTION

This document reports status and achievements for the fiscal year (FY) 01 Navy In-House Laboratory Independent Research (ILIR) program at Space and Naval Warfare Systems Center, San Diego (SSC San Diego). ILIR enables SSC San Diego to perform innovative, promising research consistent with its mission and with the policies of the Chief of Naval Research and the Department of the Navy. The ILIR program is implemented at SSC San Diego under the authority of the Deputy Executive Director for Science, Technology and Engineering and is managed by the Science and Technology Office. Total funds of $2,526,650 were provided in FY 01.

In recent years, decreases in ILIR funding induced a gradual decline in the average size of individual projects from approximately 1 work year per project to approximately ½ work year per project. This diluted the research focus of the investigators, and although productivity as measured by publications and patents did not decrease proportionately, the more limited efforts discouraged the teamwork and collaborations that promote synergistic progress. To counteract this trend, SSC San Diego began an initiative in FY 00 to increase the impact of ILIR by encouraging team projects and by increasing the average size of all projects selected. The team projects are funded at approximately $300K per year and generally last for 2 to 3 years. The rest of the program comprises smaller projects, each funded at $100K to $150K per year, up from previous averages of approximately $80K each. The intent is to fund the most mission-critical projects at high levels to enable exceptional impacts, and to fund all projects at adequate levels to generate useful results. Consequently, a smaller number of projects overall were funded in FY 01 than were funded in previous years.

The restructuring initiative has produced significant increases in average project size: in FY 99, there were 29 projects with an average funding of $77K; in FY 00, there were 28 projects with an average funding of $97K; in FY 01, there were 17 projects with an average funding of $149K; and for FY 02, 17 projects have been selected, with an average funding of $148K.

Three team projects were funded in FY 01: *Knowledge Mining for Command and Control Systems; Chaos Control and Nonlinear Dynamics in Antenna Arrays;* and *Robust Waveform Design for Tactical Communication Channels*. The *Knowledge Mining for Command and Control Systems* project was completed in FY 01. The other FY 01 team projects are continuing in FY 02, and a new team project, *Micro-Electro-Mechanical Systems Ultra-Sensitive Accelerometer (MEMS USA)* was added in FY 02.

In terms of productivity statistics, the FY 01 ILIR program was highly successful, with a total of 85 papers/proceedings/books/dissertations published or submitted and 57 presentations made by SSC San Diego ILIR investigators. There were also 4 ILIR-related patents, 13 patent applications, and 24 patent disclosures produced during FY 01.

Significantly, the restructured ILIR program has proven to be an effective workforce-shaping tool:

(a) Four of the FY 01 principal investigators are participating in graduate-degree programs: three at the Naval Postgraduate School and one at the University of California, San Diego. Their research under ILIR complements and supports their educational pursuits.

(b) The FY 00 and FY 01 programs each included one project with full-time participation by a postdoctoral research associate. Both associates have completed their appointments and are continuing to do research at SSC San Diego, one as a contractor and one as a new-hire.

(c) Four Ph.D. students at the University of California performed summer research under the *Robust Waveform Design for Tactical Communication Channels* project, and this collaboration has resulted in bringing aboard a new-hire Ph.D. scientist.

(d) In the planned FY 02 program, four of the principal investigators are recent-hire Ph.D. professionals, all of whom received their doctoral degrees in 1999. The opportunity to perform original, self-directed research helps to mature and sustain their scientific skills.

Because the ILIR program comprises basic research, the impact on the Fleet occurs over a period of years or decades, with many impacts being an indirect and cumulative result of contributions to scientific knowledge. While most of the ILIR work leads to incremental improvements in existing components and subsystems, some projects may lead to significant new systems. Examples of potential impacts are contained in the report.

Oversight responsibility for the ILIR program was moved to the Office of Naval Research (ONR) Chief Scientist's Office in October 1999. This move resulted in a complete revision of program guidelines. The new guidelines stress increased collaboration and participation of new scientists and strongly encourage teams of investigators to work on projects of sufficient scope and risk to have a potentially significant impact on Department of the Navy (DoN) priorities. The initiatives implemented by SSC San Diego in programs for FY 00, FY 01, and FY 02 successfully and productively incorporate the new guidance from ONR.

The following table summarizes recent metrics for the SSC San Diego ILIR program.

Fiscal Year	FY 95	FY 96	FY 97	FY 98	FY 99	FY 00	FY 01
Funding ($K)	2,463	2,763	2,521	2,300	2,240	2,706	2,527
Number of projects	29	31	29	25	29	28	17
Refereed papers (published or accepted)	26	19	19	15	22	18	17
Refereed papers (submitted)	9	9	10	5	10	17	14
Books/chapters	—	—	—	3	9	1	2
Dissertations	1	—	—	—	—	1	1
In-house publications	3	4	2	2	—	3	7
Proceedings (counted in presentations before '98)	—	—	—	30	26	50	44
Presentations to professional meetings	60	38	50	42	52	62	57
Patents issued	5	6	7	5	11	6	2
Claims allowed; pending issue	2	—	2	4	5	1	2
Patent applications filed	6	11	12	11	7	11	13
Invention disclosures authorized	5	6	4	3	3	4	3
Invention disclosures submitted	7	7	10	13	17	18	21

PROJECT SUMMARIES

Command and Control

Neaconing: Network Meaconing for Improved Security

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With the advent of network-centric warfare, our computing resources are prime targets of attack. Many network attacks require that the attacker have information about the network host's operating system (OS). This information can be gained through a network scan. By making minor nondisruptive changes to our computer systems, we will disrupt and confuse potential attackers. This research examined ways of obfuscating information that can be gathered through network scanning by changing relevant system settings and modifying the OS kernel of an open source operating system (Linux).[*] The focus was to achieve a dynamic configurability that would allow the scanned host to change the information detectable to match that of a different operating system (Win NT).[*] This research found that by utilizing available, but rarely used system controls, it was possible to change a system's OS fingerprint dynamically. We also found that tools currently used by attackers require exact matches to identify a target's fingerprint. Thus, minor changes to a fingerprint will defeat current tools. This research was able to cause a Linux fingerprint to more closely resemble a Windows fingerprint, and change back and forth dynamically.

SUMMARY

With the advent of network-centric warfare, the computing resources of the Navy and Marine Corps have become prime targets of attack by adversaries of the United States. In some cases, attacks on a distributed computing system or its underlying network infrastructure necessitate that the attacker have some information about the host network operating system being used on the targeted node in the system. This information, to some extent, can be gained by a network scan.

At present, systems defenses are designed to block intrusions and limit access to stop potential intruders from exploiting known vulnerabilities of a network operating system. Unfortunately, the most dangerous intruder is an intruder who is exploiting a vulnerability unknown to those attempting to maintain and protect system integrity. This intruder can exploit an unknown vulnerability over and over again until his activity within the system is detected or the vulnerability is revealed, for example, to the general hacker community. When a system administrator becomes aware that system defenses have been compromised or are vulnerable, the administrator must decide to either shut down the service or attempt to shore up the defenses. When a security hole is patched, the potential intruder may often be able to detect that the patch was made and move on to another method of attack based on a list of actual or potential system vulnerabilities.

Before a potential intruder can exploit a vulnerability of a system, he must first gather information about the system. Every information system has a presence on the network called a "fingerprint." A fingerprint is marked by such things as the system's Internet Protocol (IP) address, the ports and services available, and the operating system. The fingerprint is evident in the network in many ways,

[*] Linux is a registered trademark of Linus Torwalds.
[*] Windows NT is a registered trademark of Microsoft Corporation.

such as messages sent in services, availability of connection ports, and content of messages. An intruder can scan a system to obtain its fingerprint and identify the operating system (OS) and services running, and then the intruder can try to match the OS and services to vulnerabilities and exploits.

One major weakness in systems today is that nodes in a distributed system can reveal too much information about themselves. Our systems faithfully reply to requests from remote nodes and volunteer reliable information as to what services are available and even what operating system and applications are being used. These accurate details are just what a potential intruder is seeking. System vulnerabilities are based on a weakness in the protocol, application, or operating system, so without accurate knowledge of the application and operating system, an intruder cannot determine if the system is vulnerable. He can only guess. A firewall may limit access to some ports, protocols, and even some types of scans. As long as a network connection of any kind is possible, sufficient details can be gathered from the target computer to reveal the OS type (i.e., NT, Solaris, Linux) and even its version (i.e., 98, NT service pack 4, kernel version 2.2.16-18).

This research examined ways of obfuscating information that can be gathered through network scans, by changing relevant system settings and modifying the OS kernel of an open-source operating system (Linux). The focus was to achieve a dynamic configurability that would allow the scanned host to change the information detectable to match that of a different operating system (Win NT). We were able to modify the OS fingerprint so it could not be definitively identified over the network. These changes removed or modified various fields and parameters of the Transmission Control Protocol/Internet Protocol (TCP/IP) packets transmitted in nondisruptive ways.

This research found that the current tools used for OS identification though network scanning are very advanced. The tools are designed to use collaborative efforts to gather as many different fingerprints as possible and allow for fingerprints to be retrieved from configuration files. Specifically, the Network Data Management Protocol (NMAP) tool had over 400 different OS fingerprints listed. Each fingerprint included a specific response description to as many as seven different packet scans. These scans attempted to exercise the OS TCP/IP stack by sending unusual, invalid, or nonsense packets to the target machine. Specific attention was given to the variable and optional field settings of the TCP/IP packet. Specifically, TCP options such as Time Stamp, Minimum Segment Size, Window Scaling, and the field Window Size revealed the most differences.

This research separated the different fingerprints into groups based on the types of differences between them. This method allowed quick identification of possible targets for which operating systems could be changed to look like each other. Differences in fingerprints were categorized as either major or minor. Major differences included responding or not responding to a scan packet entirely, or changes to the sequence number generation algorithm. Minor changes were defined by changes in the fields of the response packet and options excluding major differences. Surprisingly, there were very few major changes between the OS in the NMAP program configuration file. When considering the more common operating systems, it was found that most systems differed by not more than three major changes and six minor changes. There were 21 systems that had zero major differences and three systems with zero minor differences.

The first and most obvious minor difference was the TCP Options field of the TCP packet. Each OS implemented a different set of options, so these could easily reveal the identity of the OS being scanned. The first results were found here. There are System Controls (sysctl) that allow super-users to modify the operation of the kernel. These System Controls could disable some of the TCP options and thereby change to fingerprint. By disabling just one of these TCP options, the network scanning tools immediately failed to identify the OS of the host. This result was surprising in that only exact matches were used by the current tools to identify the OS.

While these changes quickly fooled the current tools, it was obvious that once the developers of the tools became aware of this ability, they would quickly adapt the tool to search for exact matches and the closest match. The only way to effectively confuse the scanning tools was to move closer to a false network fingerprint rather than the real fingerprint. To do this, it was necessary to continue to find ways to match the different fields of the TCP packet.

The greatest discriminator of the differences in operating systems was the TCP field Window Size. This field revealed the memory allocation that the OS had assigned to the connection created. This information is used by the TCP/IP to optimize communication. While having optimized communication is valuable, a slight decrease in performance is often an acceptable exchange for improved security. By modifying the OS kernel, the window size could be modified, not just arbitrarily, but to exactly match the window size of any desired OS fingerprint less than or equal to the current window size of the OS. This change required that a new OS kernel be compiled, but once installed, it could be dynamically changed by using the same System Controls that modified the other TCP/IP settings.

It was also possible to modify the Do Not Fragment (DNF) bit of the TCP/IP packet by changing the kernel. The DNF is an optional setting designed to help optimize routing, so changes should only change the performance of the connection. Most DNFs are used for trivially small packets.

The last field remaining to convert the Linux OS fingerprint to match that of a Windows NT OS fingerprint was the TCP Sequence Number. The Linux system used a much more secure random number, while the Windows system used a less secure one. This change is the first that would actually result in decreased security. By making the TCP sequence number less random to match the Windows NT sequence number, the Linux system would become more vulnerable to IP spoofing, hijacking, replay, and other network attacks which the random number is designed to protect against. The risk of matching this field of the OS fingerprint would be greater than the benefit, but the change is possible. It is very likely that Microsoft will eventually use the stronger sequence number generation in new OS releases or updates, since very few other operating systems still use this less secure style of random-number generation.

Making changes to the TCP/IP packets can result in increased security without changing the essential connectivity of the system. The changes identified by this research may result in some slight loss of performance. By changing the way an OS creates its TCP/IP packets to remove the OS identifiable aspect, we can limit the ability of potential attackers to identify our OS. Any change to the fingerprint of the OS will avoid an exact match of the OS fingerprint, but this benefit is only temporary. Our research has shown that it is possible to exactly match the OS fingerprint of two different commonly used operating systems. By exactly matching the fingerprint of another OS, it becomes impossible to identify the OS of the target system.

If the principles of this research are applied, potential attackers of Navy and Marine Corps computing resources would no longer be able to acquire identifying information quickly or accurately identify an operating system. Potential attackers would have to resort to statistical probability and brute force exhaustive search of all possible attacks for all potential operating systems. Such efforts would increase the probability of detection and enable further blocking or other means of censure against them. The overall operation of the networks would be unchanged except for minor changes to performance or bandwidth.

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* For further information on the RFCs, contact the author of this paper, Aaron C. Judd.

Adaptive Distributed Object Architecture (ADOA)

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Object-oriented computing is fast becoming the de-facto standard for software development. Optimal deployment strategies for object servers can vary with changes in servers, client applications, operational missions, hardware modifications, and various other changes to the environment. The goal of this project is to allow a network of computers to evolve and to have assets of this computer network optimized for these changes.

SUMMARY

Once distributed object servers become more prevalent, there will be a need to optimize the deployment of object servers to best serve the end user's changing needs. Having a system that automatically generates object-server deployment strategies would allow users to take full advantage of their network of computers.

Many systems have very predictable points in time where the usage of a network changes. These systems are usually characterized by shift changes where the manning and functions performed change from shift to shift. We propose a pro-active optimization approach that uses predictable indicators like season, mission, and other foreseeable periodic events.

The proposed method profiles object servers, client applications, user inputs, and network resources. These profiles determine a system of equations that is solved to produce an optimal deployment strategy for the predicted upcoming usage by system users of computers and servers.

Complex computer systems are made up of computers, the networks that connect these computers, the software that runs on these computers, and the users who interact with the applications. The systems tend to be heterogeneous in the hardware and software that make up their structure. The functions these systems support are also diverse.

System engineers always want these computer systems to perform at peak efficiency. However, with the constantly changing environment that characterizes these systems, peak efficiency is difficult to maintain.

When these systems serve a set of users that is known and limited, then the possibility of matching the system to the changing environment is achieved. By knowing ahead of time that a limited number of users can access the system, assumptions can be made about queuing delay, and thus reasoning about this environment is possible. Even a simplistic model of this environment can lead to large gains in performance.

To prove this hypothesis, a methodology was introduced for implementing a model of a distributed, object-oriented system with a known set of users on a heterogeneous environment of hardware. Different scenarios reflecting different manning schedules and hardware and software changes were input into the model. The results of these model runs were different deployment assignments for the object servers.

These scenarios were then tested with real software on real hardware in a test environment. Measurements of all possible deployments were collected and compared. The results showed that substantial performance enhancements could be achieved.

The advances of object-oriented technology in the past decade have lead to worldwide acceptance of its principles. Today, numerous developers design their systems by modeling the problem domain in terms of communicating entities called objects. Object-oriented systems tend to be more intuitive, be easier to maintain, and also allow for more re-usable code.

The future of computing is heading for a universe of distributed object servers. The evolution of object servers to distributed object servers will parallel the evolution of the relational databases. Over time, object servers will provide functionality to more client applications than their original applications, just as relational databases were used by more applications than the original application. In both cases, systems optimized for the original application may not perform well for the new applications. Tools that allow a programmer to model an object and create object servers with all the necessary infrastructure code needed to work as a distributed object server will soon be available. Such progress will lead to an explosion in the number of object servers available to client applications.

A user’s network of computers will be in a constantly changing state. Object servers, applications, hardware, and user preferences will be in a constant state of flux. No static deployment strategy can adequately take advantage of the assets accessible on the network in such a frequently changing environment. In many cases, there exist predictable points in time where users will know how their network of computers will change. These predictable points in time are usually scheduled. By allowing users to take advantage of these scheduled changes, the system can be better utilized.

No system can accurately predict user interaction with a system. Two separate users performing the same job will interact with a system differently. The same user may interact differently while performing the same job. For these reason-and-combinatorial-explosion problems, a more dynamic software-engineering approach must be taken instead of a static computer-science approach. The alternative is a deployment strategy that is dictated by the system engineer’s view of how the system will be used. Of course, the system engineer doesn’t revisit this strategy every time hardware, software, or user interactions change. The goal is to make better deployment choices without the need for a system engineer, since many of these changes will take place without the knowledge of a system engineer or the budget to employ one.

The results of the Java Remote Method Invocation (RMI) experiments lead to some interesting results. The predictions made by the model were very accurate, leading to good choices for server deployment. However, more striking conclusions are drawn from looking at groups of experiments.

Although the model does a good job of predicting performance for a single point, the true strength of this approach is chaining these points together. By taking advantage of changes to the system at predictable points in time, we can do better than any single statically assigned server placement.

If we assume that we have a shift schedule that has the following six unique manning requirements over the duration of the schedule, then we can initiate object-server redeployments to coincide with the shift changes. The shaded areas in Table 1 indicate the deployment pattern recommended by the model. The numbers in the matrix are the actual measured values for these deployments.

Table 1. Shift changes.

PAT	SERV A	SERV B	SERV C	ROLE 1	ROLE 2	ROLE 3	R2 (4)	R3 (3)	R1 (28)
2	GIGA	GIGA	BR733	899.34	5530.33	8266.52	11746.10	13925.95	4964.73
3	GIGA	BR733	GIGA	960.81	6417.17	7802.17	11711.42	13066.21	4333.77
4	GIGA	BR733	BR733	1079.64	6686.38	9124.94	14333.22	20415.47	3789.35
5	BR733	GIGA	GIGA	1140.80	5953.02	7413.34	11335.30	14614.58	7005.97
26	SIX	GIGA	BR733	1355.59	6752.50	8625.44	10544.22	13839.30	11117.11
27	SIX	BR733	GIGA	1306.69	7380.83	8259.05	12569.52	12488.02	12042.34

We are only interested in the six deployment patterns listed in Table 1. If we were to institute a static deployment for our system, then we would be forced to pick just one of the deployment patterns listed above. The system engineer would be forced into some logic that mitigated a worst-case scenario.

However, since we have the ability to reason about different manning schedules, we can take advantage of this capability. By allowing the system to adjust the location of its object servers at shift changes, we gain substantial improvements to the system.

By comparing the model's recommended deployment pattern versus the other six deployment patterns in Table 1, we can quantify this improvement. By dividing the measured performance of the model-predicted patterns by the measured performance of the other patterns in the same column, we get the performance improvement for each shift. Table 2 contains these values.

Table 2. Shift improvements.

PAT	SERV A	SERV B	SERV C	ROLE 1	ROLE 2	ROLE 3	R2 (4)	R3 (3)	R1 (28)
2	GIGA	GIGA	BR733	–7%	0%	10%	10%	10%	24%
3	GIGA	BR733	GIGA	0%	14%	5%	10%	4%	13%
4	GIGA	BR733	BR733	11%	17%	18%	26%	39%	0%
5	BR733	GIGA	GIGA	16%	7%	0%	7%	15%	46%
26	SIX	GIGA	BR733	29%	18%	14%	0%	10%	66%
27	SIX	BR733	GIGA	26%	25%	10%	16%	0%	68%

Interesting to note is that we are only comparing deployment patterns that are of high probability of actually being used. Only one entry in the table has a negative value; all other entries have a substantial performance improvement. Clearly then, Table 2 illustrates that any organization with known manning schedules that fluctuate would benefit from this approach.

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Knowledge Mining for Command and Control Systems

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This project researched the process of feature creation in support of data mining. The approach taken was to develop a Knowledge Amplifier by Structured Expert Randomization (KASER), which is, in effect, a qualitatively fuzzy expert system shell. The KASER is predicated on Gregory Chaitin's Theory of Randomization. It is especially useful in diagnostic systems and for fault detection because it creates a virtual rule space that is much larger than the real rule space. Thus, the cost of knowledge acquisition in expert systems is greatly reduced. The KASER is predicated on the use of ontologies, i.e., the antecedent and consequent trees are object-oriented and operate through a single inheritance mechanism. We developed tools that support the creation and maintenance of those trees. This method results in an intelligent system that fails softly and that also provides a possibilistic mechanism that dynamically learns to predict the possibility of any induced rule. The KASER entails a more complex inference engine than conventional expert systems. Consequently, qualitatively fuzzy expert systems cannot realistically support backward chaining.

SUMMARY

First-generation expert systems are production systems where the knowledge base and inference engine are disjointed. Second-generation expert systems are defined as those with a rudimentary capability for learning. Here, learning can be performed through the manual interpretation of grids or by user query. Third-generation expert systems go one step further [1]. They provide for learning by the rule base through the use of deductive and inductive processes.

Consider the theory of randomization [2–6], which entails reducing information to its simplest form through compression techniques. Deduction represents the most common form of information compression. In other words, why store all instances of a knowledge predicate when they are subsumed by a common generalization? Similarly, induction represents a fuzzy form of information compression. Here, while an instance of a knowledge predicate is saved, one tries to extend the scope of that instance through generalization operations. Unlike the case for deduction, error is inherent to inductive processes. Nevertheless, when corrected, the effect propagates nonlinearly—thereby justifying the allowance for error in many application domains [7].

DECLARATIVE OBJECT TREES

Declarative object trees are used to represent knowledge in a Knowledge Amplifier by Structured Expert Randomization (KASER). There are few limits placed on the operational domain, since the KASER is a shell. One limit, however, is that the more symmetric the domain, the more creative the KASER can be. Thus, KASERs possess no inherent advantage for learning, for instance, random historical information; however, they can be far more applicable to symmetric domains such as mathematics, engineering, or the naive qualitative physics, for example. Here, the system is far more likely to induce correct new knowledge. Of course, no nontrivial domain is entirely random or entirely symmetric [3].

Declarative object trees are used as follows. In the antecedent tree, instances fall under an object, while generalizations lie over it. The degree of specialization or generalization is determined by a tree search, which is limited by a user-defined squelch. In the consequent tree, a certain quanta of knowledge will take one to a certain object consequent. Additional knowledge will take one to an instance of that object, if available. For example, the fact that it is cloudy and the barometer is falling will take you to the fact that precipitation is likely. Then, given that it is below freezing, the proper instance of precipitation will be snow. Notice how the use of the consequent object tree maximizes the potential for information reuse. Consequents may be selected as a sequential composition. Objects selected from the antecedent menu serve as the conjunctive context. KASERs can operate with words, phrases, object-oriented functions, and procedures. For example, a procedure that enumerates prime numbers is an instance of one that enumerates odd numbers.

Declarative object knowledge is acquired through interaction with a knowledge engineer. This process is ongoing for open domains. Just as one can write a simple program and proceed to evolve it, so too can one evolve the declarative object trees. The more evolved the trees, the more accurate will be the induced knowledge, where domain symmetry is held constant. For example, the conceptual object, “apple” may be evolved into at least two object subclasses: “red apple” and “green apple,” etc.—depending on the application.

Our KASER is replete with tools for copying objects, moving objects, pasting (i.e., single objects), deep pasting (i.e., copying whole subtrees), finding object nodes, suggesting next nodes based on $k = 1$ level of look-ahead, etc. For example, if one is running a preflight checklist, then after checking the rudder, the system will look ahead one-step and suggest checking the elevator. This procedure helps to prevent omissions in complex contextual specifications.

EMPIRICAL LEARNING RESULTS

Figure 1 provides a graphical depiction of empirical KASER learning results for the domain of automotive diagnostics. The most stringent test of learning occurs where the General Stochastic Measure (GSM) is greater than zero and the yielded consequent is deemed to be correct. In other words, let us investigate the validity of virtual rules arrived at by inductive processes.

The KASER was initialized for the Honda Accord. Note that prior to rule acquisition, the system must incorrectly predict a rule consequent. Here, only 2.56 percent of the 50 contexts presented to the system, which resulted in a GSM > 0, were deemed to yield the correct consequent by an Oracle [8]. The poor performance is attributed to the sparsely populated knowledge base. We chose the Nissan for our next automobile because it is quite similar to a Honda in all salient features. The rule base at this point consists of 141 Honda rules. We proceeded to train the system on Nissan rules. The KASER gave the correct consequent for 62.22 percent of the Nissan contexts, which resulted in a GSM > 0. This striking improvement in performance may be attributed to knowledge transference from the Honda rules. In all, 120 rules were supplied for the Nissan.

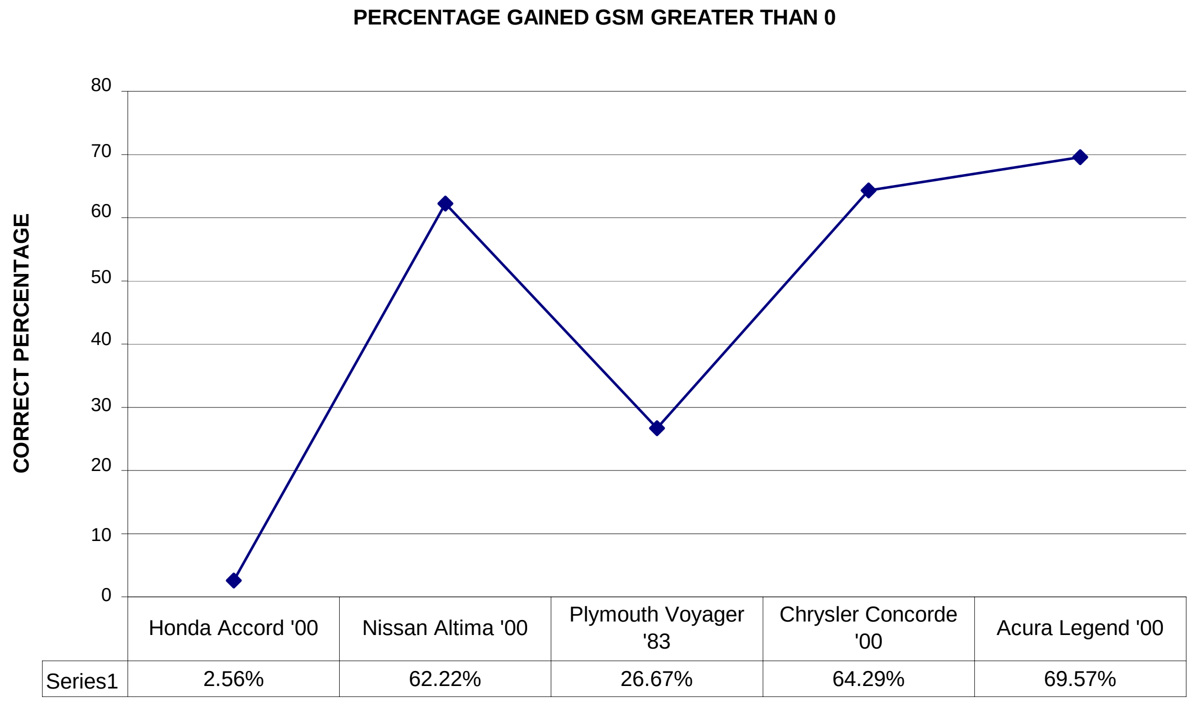

Figure 1. Knowledge transference in the KASER applied to automotive diagnostics.

Next, a vehicle that is relatively random when compared to the Honda and the Nissan was chosen. Such a vehicle is the Plymouth Voyager. Experiments revealed that only 26.67 percent of the Voyager contexts, which resulted in a GSM > 0, gave the correct consequent. In all, 164 rules were supplied for the Voyager. The drop in performance was to be expected and may be attributed to the relative lack of symmetry between the Voyager and the two cars. However, note that the percentage correct is still greater than that for the Honda due to transference.

The Chrysler Concorde is similar to the other cars. Next, the KASER gets 64.29 percent of the Concorde contexts correct, which resulted in a GSM > 0. In all, 161 rules were supplied for the Concorde. Here, the greater than 2-percent improvement in the percentage correct over the Nissan may be attributed to transference from the Voyager.

Finally, the Acura Legend, which is similar to all the other cars, gets 69.57 percent of the Acura contexts correct, which resulted in a GSM > 0. In all, 154 rules were supplied for the Acura. Here, the improvement may be attributed to domain symmetry. The KASER clearly has not lost its knowledge of cars and appears to be approaching an asymptote for inductive accuracy. Once the knowledge base has been populated (e.g., as shown), this asymptote is more a function of the degree of inherent domain symmetry. The supra-linear propagation of corrections is evident from the fact that knowledge gained from a single domain transfers to a plethora of similar domains. Clearly, as demonstrated by Figure 1, learning about cars even facilitates learning about vans and vice versa.

CONCLUSIONS

The knowledge-acquisition bottleneck has been and will continue to be broken. The KASER offers itself as a new, more creative type of expert system. This third-generation expert system computes with words and employs qualitative fuzzy reasoning. It also may be said to fail softly and, for this reason, is not brittle. KASERs cannot be realized through the exclusive use of predicate logic since they embed an inductive component. Furthermore, KASERs can capture and otherwise represent virtually all of the domain knowledge possessed by a knowledge engineer. KASERs can also predict their own likelihood of error. They reason through a gradient descent or ordered search algorithm, which serves to minimize the predicted error.

The KASER has exhibited domain transference and supra-linear learning, which bear proportion to the inherent degree of domain symmetry. The KASER introduces the use of declarative object trees in expert systems. Such trees facilitate the capture of object-oriented semantic relations among rule predicates and, thus, serve the processes of metaphorical explanation as a consequence.

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Information Fusion with Entropy and Conditionals (IFWEC)

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The original objective of this project was to incorporate the syntax and operations of the Calabrese algebra of uncertain conditionals into the entropy-driven expert system called SPIRIT, developed by Professor Wilhelm Rödder. The approach was to obtain the source code and permission to modify it to explicitly include the algebra of conditionals. The coding alterations were made, and an updated version of SPIRIT was demonstrated.

SUMMARY

As information has proliferated with the computer revolution, the need for adequate processing and interpretation of that information has lagged for various reasons such that there is a very serious bottleneck in the U.S. Navy's information processing. Human beings cannot combine rapidly changing, uncertain information about situations and make quantitative assessments of the likelihood of events of interest given that new information. Nor have humans been able to program their computers to do such quantitative assessments because such computations run straight into well-known complexity problems when standard Bayesian probability computations are attempted on even simple problems. Consequently, other approaches to uncertain information processing have been attempted such as the fuzzy sets of L. Zadeh and the so-called belief theory of Dempster-Shafer. However, since these methods make compromises with logic in exchange for computational tractability, they run into inconsistencies without warning and offer nothing in the way of estimates of how accurate they are for any particular computation. Thus, their use, while practical in some cases, is worrisome in important matters such as military operations. More recently, the Bayesian Nets of J. Pearl have been used to represent and manipulate uncertain information. However, here again, complexity makes this method impractical for handling new variables or values (or even just changes due to information updates) because they require the whole network to be recompiled and unknown information to be estimated in order to make computations.

One development that offered new hope for adequate processing of uncertain, conditional information was the algebra of event fractions developed at SSC San Diego and earlier by the principal investigator (PI), Dr. Philip Calabrese. In a multi-year DoD contract, these event fractions, which adequately represent and combine explicitly conditional information, were implemented in the University of Paderborn, Germany, programming environment called Multi-Processing Algebra Data (MUPAD) tool. While this effort was mathematically successful, allowing the rich syntax of the algebra to be applied to conditional statements involving variables and their values, complexity problems again bogged down the computations, making the development impractical to use.

Fortuitously, about the time this complexity problem was encountered, the PI became aware of the work of Professor Wilhelm Rödder of Fern University in Germany. Using an entropy approach that is slowly gaining more and more recognition around the world, Professor Rödder developed an expert system that can make rapid calculations without sacrificing logical consistency. Unlike Bayesian calculations, which attempt to find *all* possible probability distributions that are consistent with the given information, the entropy method determines *one* probability distribution that assumes no dependencies between variables except those explicitly stated. The method finds the most likely Bayesian probability distribution satisfying the initial constraints. Thus, this entropy method can *rapidly* find the most plausible probabilities for events of interest given new information. A demonstration of Professor Rödder’s software called SPIRIT leaves no doubt about the usefulness of his development, and now Professor Rödder has recognized how the Calabrese algebra of event fractions can enlarge the syntax of his system and allow deductions with quantitative estimates of the likelihood of those deductions.

The project received some coding help to implement the syntax and operations of the Calabrese algebra of uncertain conditionals in SPIRIT. This allowed more work on the fundamentals of deduction and inference with uncertain conditionals. New results were obtained concerning how to generate the deductions implied by a set of uncertain conditionals, where the type of deduction can be any of several identified for conditionals. In addition, the operations were extended to functions in general, including conditional random variables and conditional expectations, whose domains may overlap. This type of operation is useful when information is conditional and so applicable on different domains.

The potential naval significance of this work is great. Efforts to automatically calculate the deductions and inferences of a military situation described by a set of variables and values and a set of rules and other information have been elusive due to the complexity of such calculations. The maximum entropy principle applied to military situations allows for the rapid calculation of the most plausible probability distribution given the known information. Putting together such information will allow inferences to be made in real time concerning threats that are likely in view of that information.

Integration of Complex Information

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The project goal is to define a mechanism to allow complex nonspecified information to be integrated and utilized. The method being explored uses open hypermedia architectures and lightweight inference to manage and utilize information. Successes to date have included the definition of a hypermedia framework that can be used for (a) intelligence analysis and plan description and tracking, (b) identification of two inference strategies to be explored, and (c) the successful transition of the hypermedia framework to a development project. During this final year of the project, the focus was to transition the capability into command and control and intelligence systems.

SUMMARY

Command and control involves three fundamental processes that fit together in a tight cycle. Situation analysis provides the context on which to act. Decisions are made based on the analysis results. These decisions constitute planned movements, engagement orders, and many other possible actions. Decisions must be communicated to those who are to carry out the actions. The results of these actions are observed and folded into a new situation analysis.

As command, control, communications, computers, intelligence, surveillance, and reconnaissance (C^4ISR) systems have evolved, system integration has been the general theme. Stand-alone systems, each with its own database, were first interfaced to allow some transfer of data. Data-management schemes were implemented to provide some consistency among databases and operational units. System federation gradually allowed multiple applications to run on users' workstations, preventing the need for specialized hardware and support software for large numbers of individual systems. The current state of system integration not only allows multiple applications to share hardware, operating system, and network platforms, but also uses a layered-service architecture to eliminate redundancy of some capabilities.

The evolution of system integration has broadened the stovepipes that were so narrow in previous system generations. The resulting view is of a few very broad systems made up of many small applications, any of which, may be accessible through the workstation in front of the user. Some applications work on common data managed through centralized services. However, many categories of data still form separate stovepipes as they are maintained in separate data servers due to their differing technical natures and programmatic backgrounds. It is left to the users to associate the tactical situation shown in one application with the results of a logistical query conducted through another.

INFORMATION COMPLEXITY

The focus on systems integration ignores the true goal in decision support. It is the information that is of ultimate value to the decision-makers. Integrating the information is the next step. However, military information is not a simple matter of collecting and crunching sales and inventory figures from various branch offices as found in data-warehousing applications. The domain of the military environment is complex. The variety of concepts, events, and situations that can be described subjectively or measured and reported objectively is probably limitless. No ontological study can *a priori* determine all possible data types needed to describe the military environment. Therefore, information integration is not going to be completely accomplished through bringing all data into a relational or object database.

A PATTERN OF ANALYSIS

In researching the requirements for an intelligence support system for the Defense Intelligence Agency (DIA), a pattern of analysis was uncovered that was common to those used in some other domains. The primary feature of this pattern is that an analyst's role is to create associations among existing data. An analyst rarely creates data, but searches, filters, and reviews all available information. While doing so, the analyst forms networks of related information.

Current practice involves DIA intelligence analysts spending a portion of their time building up a private model of their area of expertise. The remainder of their time is spent responding to queries from DIA's various customers. The responses typically take the form of linear essays. Analysts also periodically produce background reports on particular matters of interest. These reports also take a strictly linear book-like form even when delivered over a computer network.

The results of the current approach included the following problems:

- The products were static or updated on a paper publishing timeframe.
- Customers with local information were unable to share with others.
- Only a particular question was answered, even if it was not the correct question.
- Analyst turnover caused a large loss of knowledge.

As a result of these insights, work was initiated to find a way of recording the knowledge being built by the intelligence analyst and communicating this knowledge to intelligence consumers. The goal was to move away from the linear essay and its strict segregation of reader and writer roles to a more collaborative method of communication that would allow for continuous updates of the knowledge jointly held between the intelligence agency and its customers.

RECORDING DECISIONS

Decisions also take the form of associations among data or information elements. A classic example may be the order for a surface combatant to engage a hostile aircraft. The decision-maker did not create the aircraft or the positional and attribute data held on that aircraft. Likewise, the surface combatant's information was not generated by the decision-maker. The value added by the decision-maker is that an engagement relationship (perhaps with other amplifying information) should exist between the two.

As the data on the two combatants changes, the association must be reviewed but is not necessarily invalidated. Likewise, a reversal of the decision changes the relationship among the combatants but does not change any of their individual data. This fundamental distinction between the structural representation of the associations among concepts or real-world objects and the content that describes them is common between the knowledge created by analysts and decision-makers.

USING THE KNOWLEDGE

The intelligence analysis tool built for DIA allows for the storage and retrieval of information from the knowledge base. If this technique is to be used for command and control purposes, the knowledge held in the structure of the hypermedia must be able to be extracted and used. This knowledge can best be described in terms of properties. Some simple properties regarding connectedness and reachability have been defined for the hypermedia.

Communications

Chaotic Wideband Antennas

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This research pursues two complementary themes: the adaptation of control of chaos techniques to develop antennas capable of operating across an enormous bandwidth, and the development of nonlinear antennas incorporating analog signal processing at the plane of radiation collection to perform beam steering and beam forming. In the past year, extensive progress has been made toward adapting chaos control algorithms for high-speed applications. After extensive simulations of the algorithm, further refinement and simplifications were realized via experiments. The successful demonstration of a chaos control algorithm illustrates the ability to select frequencies across the wide spectrum inherent in chaotic systems. In the complementary research on the active nonlinear antenna project, a complete theoretical treatment on combining amplitude and phase dynamics of non-identical oscillators has been made. This approach removes the constraints of the separation of amplitude and phase dynamical time scales, allowing for the possible creation of compact array antennas and strong side-lobe suppression, while preserving beam-steering and beam-forming capability. These results are highly relevant to the Navy's need for compact, wideband-width, high-frequency multifunction antennas.

SUMMARY

The DoD recognizes the need for a new generation of advanced antennas for communications and surveillance. In particular, naval combat systems and communications links are transitioning to high-bandwidth phased-array antennas. In radar applications, the antenna must provide wide instantaneous bandwidth for long-range and high-resolution target detection and discrimination. In C^4I systems, the twin goals are increased data rates while combining the bands of operation into a single multifunction antenna. High-frequency operation, mutual coupling, and high power operation are known to generate nonlinear responses in (*a priori* nonlinear or quasi-linear) antenna arrays. Recent research has shown that advanced nonlinear arrays can produce dramatic improvement in signal detection while providing robust operation in the presence of noise, and may produce an extremely wide operational bandwidth. These nonlinear dynamic systems can be made far less complex than their traditional linear counterparts through the judicious application of chaos control techniques. All these advantages are achieved by incorporating *nonlinear dynamics* rather than limiting the system to linear quasi-steady-state operation.

Over the past 30 years, advances in numerical and mathematical analysis of nonlinear dynamics have yielded significant progress in the understanding and control of complex systems. Both theoretical research and experiments revealed novel behaviors unattainable in linear systems, including synchronization, noise-induced coherence, and chaos. Although the present understanding of complex systems is far from complete, the field is sufficiently mature to begin the transition from basic research to applied engineering. To balance the need for new and advanced designs with the need for reliable products, a new design methodology must incorporate, in a progressive manner, nonlinear dynamics.

This research pursues two major objectives. The first objective is to study specific nonlinear response characteristics in coupled dynamical array systems in order to develop techniques to control, synchronize, and exploit such phenomena to produce a high power signal with sharply defined frequency tunable over a broad range. The second objective is to investigate beam steering, beam shaping, and performance enhancements of compact non-identical oscillator arrays by exploiting the amplitude dynamics in addition to the phase dynamics. The project is expected to transition to advanced wide-band antenna design.

The first-year goal for constructing a nonlinear array for a broadband nonlinear antenna was designing a chaotic oscillator that can be controlled to exhibit periodic dynamics. Two candidate nonlinear oscillators were designed, fabricated, and tested: the modified van der Pol and the Colpitts. Significant progress toward adapting chaos control algorithms for use at high speeds was also made during the past year. Extensive simulations of a single chaotic Colpitts oscillator refined the control algorithm, which, in turn, was applied to the experimental system. Figures 1(a) through 1(d) illustrate the successful capture (control) of any desired orbit in the chaos. Research continues on simplifying the control technique further to reduce latency and raise the frequency of operation. Additionally, new simulations and experiments are in development to study the synchronization properties of an array of chaotic oscillators.

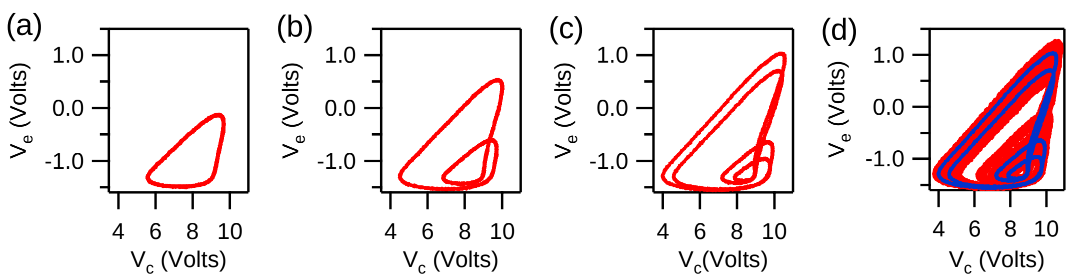

Figure 1. Using the chaos control algorithm, the myriad unstable periodic orbits existing in chaos can be stabilized, turning random motion of chaos into a periodic motion of any desirable frequencies. (a) Period-1 orbit plugged from chaotic motion. (b) Controlled period-2 orbit. (c) Controlled period-4 orbit. (d) The control period-4 orbit (blue) overlays against the chaotic orbits in the background (red).

Complementing the chaotic antenna project is the nonlinear active antenna. The nonlinear active antenna project leverages recent advances in active antenna design, active electronics integrated with the passive radiative elements, and the theory of non-identical oscillators to generate beam steering and beam forming across an array of nonlinear oscillators. Additionally, compact arrays, antennas with element spacing significantly smaller than a half-wavelength, are possible by directly coupling nonlinear elements. Progress for this year includes completing theoretical work on combining the phase and amplitude dynamics of non-identical oscillator arrays, removing constraints on the separation of amplitude and phase time scales, numerical studies of AM and linear FM modulation, and experimental validation of the phase dynamics with both a low-frequency microelectronic array and an RF antenna array. Research continues on validating side-lobe suppression and monopulse operation (phase difference versus phase sums).

Due to the scope of the project to develop an advance nonlinear antenna, analog Very Large Scale Integration (*a*VLSI) is used as a common experimental test bed. As a direct result, the project benefited from the relatively low cost of custom designs by using tested fabrication processes via the metal-oxide-semiconductor implementation system (MOSIS) foundry system. These designs combined time-tested traditional circuits with more advanced designs and expertise that has been born out of the *a*VLSI engineering community.

The design approach, making use of metal-oxide-semiconductor field-effect transistors (MOSFETs) operating in the sub-threshold region, allows operation at current levels of a few nano-amps without loss of functionality. Additionally, the floating-gate MOSFET performs analog computation at the device level or alternatively acts as a nonvolatile memory element, making extremely compact circuits possible. The goal is to combine these devices into specific task-oriented designs, such as compact antenna arrays, while making the designs adaptable or reconfigurable, by virtue of the programmable floating-gate, low power, by making use of sub-threshold current levels, and compact by employing the device-level physics of the design. Figure 2 illustrates the two current *a*VLSI designs, the nonlinear beam-steering array (2a-b) and the nonlinear beam-forming array (2c-d).

The ultimate goal at the end of the research program is to develop a nonlinear antenna capable of operating with extreme wide band by using the inherent property in the chaotic system. By using a control algorithm to capture and stabilize the unstable periodic orbits existing in the chaos, the chaotic system can be made to operate at any selective frequencies. By combining the wideband feature with the dynamics of non-identical array oscillators as illustrated in the theoretical work mentioned previously, a nonlinear antenna has the ability to beam steer and beam shape as well as switch frequency of operation. Such a realization hinged on the ability to intelligently manipulate coupled, *nonlinear* oscillator arrays. This marked a significant divergence from traditional design practices because of the deliberate incorporation of nonlinear effects and the exploitation of mutual coupling between radiating elements. Antennas developed with this kind of an approach possess several attractive features including the elimination of feed networks, phase shifters, and the beam-steering computer. Beam steering is accomplished through a network of low-power, DC control voltages. Moreover, the design is not inherently limited to a particular portion of the frequency spectrum*; it is as relevant to sonar applications as it is to devices operating at terahertz frequencies*. Consequently, this methodology enables optimized design producing compact, wideband, low-cost, lightweight, and low-power antennas.

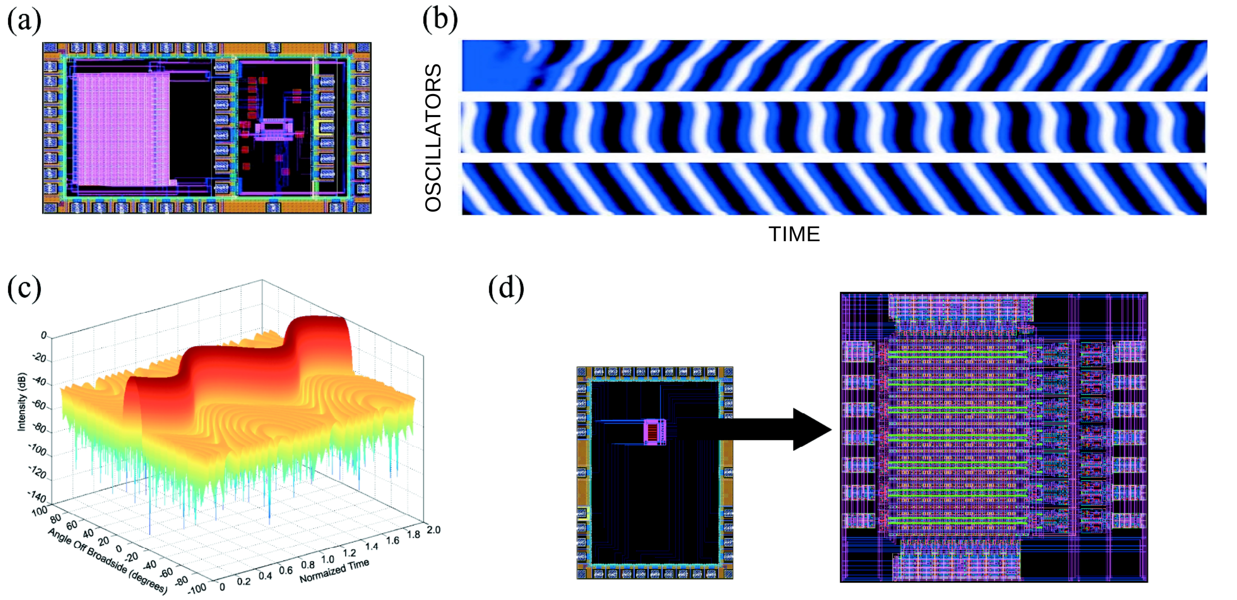

Figure 2. (a) Complementary metal-oxide semiconductor (CMOS) implementation of nearest neighbor coupled nonlinear oscillator array (13, 20 element chains) in a 0.35-µm process (left side) and a first generation globally coupled array using floating gate nonvolatile memory (right side). Floating gates serve as convenient programming and coupling circuitry that accommodate adaptive coupling topologies such as a local, global, or "Small World Networks" (the insertion of random long-range connections into the nearest neighbor network). (b) Numerical simulation of beam steering using model CMOS oscillators matched to the 0.35-µm process. The oscillator model and parameters are obtained from direct measurements from (a). In the figure, time progresses from left to right and amplitude is normalized to a black-blue-white scale. Dynamical beam scanning is achieved by frequency detuning the end (top/bottom) oscillators in the array. (c) Simulated far-field pattern of 1 x 17 nonlinear array, similar to (b). Beam steering and forming is accomplished by dynamic interaction between elements in the array, eliminating the need for a feed network and beam-steering computer. In addition, significant side-lobe suppression is achieved by controlling the amplitude dynamics. (d) Second-generation globally coupled array using floating gate nonvolatile memory (in fabrication). The array generalizes to the locally coupled array and allows individual coupling strengths and amplitude tuning by using long-term memory (floating gate).

Robust Waveform Design for Tactical Communications Channels

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This project's objective is to develop the analytical tools required to evaluate the tradeoffs in data rate and security that are fundamental to the design of robust tactical communications networks. The critical parameters of the system are the waveform design, the transmitter and receiver antenna gain and directivity, the interference parameters, and the characteristics of the tactical communications channel. Our approach has been to define the bit-error rates of several candidate waveforms as a function of the energy per bit, the number of bits per symbol, and other key signaling waveform parameters for candidate transmitter/receiver architectures. This analysis permits the evaluation of the tradeoffs in data rate and detectability of the transmitted waveforms. Nonlinear adaptive signal-processing techniques are being developed to mitigate the effects of hostile interference. This project addresses current naval needs for tactical littoral communications for the Marine Corps 2010 Communications Architecture for Operational Maneuvers from the Sea (OMFTS). Major results to date include (1) the development of analytical tools that accurately predict the performance of prototype low-probability-of-detection (LPD) waveforms; (2) the development of nonlinear signal-processing techniques that maximize interference suppression with minimal distortion of the desired signal waveforms; and (3) the definition of significant benefits realized through the use of multiple antennas at the transmitter and receiver, even in cases where the limited size of the receiver results in significant coupling between the antenna elements.

SUMMARY

The revolutionary advances in modern commercial telecommunications technology provide significant promise for advances in the operational efficiency of military systems and for improved quality of life for the sailors and Marines responsible for conducting operations around the world. However, these systems also provide a significant challenge for the Fleet and the Marine Corps because the commercial systems that provide real-time, worldwide access to multimedia information via the Internet often do not provide the security features required in tactical operations. A critical requirement for rapid access to video and other information is the use of high-data-rate communications networks operating at rates exceeding 1 Mbps. Conversely, low-probability-of-detection (LPD) systems often operate at data rates as low as 10 bps to minimize the probability of detection by an adversary.

SSC San Diego is involved in numerous research and development efforts to provide high-speed communications capabilities to the Fleet. We also have a number of other efforts that are focused on providing communications security. One such effort is an Office of Naval Research (ONR) 6.2 effort to provide LPD communications for the Marine Corps. These LPD links are a requirement in the Marine Corps 2010 Communications Architecture for Operational Maneuvers from the Sea (OMFTS). A prototype system was developed to meet this requirement. In addition a Cooperative Research and Development Agreement (CRADA) with Harris Corporation and Intersil is in progress to transfer the technology to the PRISM chipset (a commercial standard). Unfortunately, the realization of this transfer is impeded by the lack of a common baseline to meet the commercial requirements for high data-rate while still maintaining a satisfactory level of LPD for military operations. It is the goal of this project to provide the analytical tools that will allow security and data-rate tradeoffs to be evaluated on a common baseline and to define the waveforms and transmitter and receiver design parameters that will satisfy tactical military communications requirements without sacrificing data rate.

A number of references on the desirable waveforms under consideration as a standard for the High Data Rate IEEE 802.11 Extension are posted on the Intersil Web site http://www.intersil.com/design/prism/papers/index.asp

The waveforms under consideration include M-ary Orthogonal Signaling (MOS), Cyclic Code Shift Keying (CCSK), Pulse Position Modulation (PPM), Orthogonal Frequency Division Multiplexing (OFDM), Orthogonal Code Division Multiplex (OCDM), M-ary Quadrature Amplitude Modulation (M-QAM), and Complementary Code Keying (CCK). The comparative performance of each of these is discussed in the above papers relative to the current Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK) modulations that are the current IEEE 802.11 standards for the 1 Mbps and the 2 Mbps data modes. In addition, the importance of antenna diversity in achieving reliable performance in fading channels is also documented in these papers.

The modulation format used in the LPD prototype developed at SSC San Diego for ONR 313 uses the CCSK modulation. CCSK is also used in Joint Tactical Information Distribution System (JTIDS) and other military radio modems. A principal advantage of CCSK modulation is the implementation simplicity. One of our key results is that we proved that the probability of error performance for CCSK is equivalent to that of MOS. This result is significant because CCSK requires only the computation of the Fourier Transform of the received signal plus noise, F(r), followed by an inverse transform of the product of F(r) and the complex conjugate of the transmitted code, F(c). By contrast, implementation of MOS requires correlation of each of the M-orthogonal functions with the received signal plus noise.

The differences in implementation thus become significant as M increases for MOS modulation. This factor is especially important for LPD applications because it is necessary to maintain low levels of transmit power in order to avoid detection by a hostile intercept receiver. CCSK or MOS can do so by increasing the length of the code to increase the coding gain. Under the ONR 6.2 program, field tests were performed with the prototype CCSK receiver in 1999. These tests verified that reliable communications at 25 bps could be achieved over a 48-mile line-of-sight channel between Mount Palomar and Building 40 on Point Loma using a transmit power level of 25 microwatts and 9-dbi directional antennas at the transmitter and receiver and a code length of 65,536 bits. The differences in implementation complexity between CCSK and MOS for codes of this length are significant.

One of the major advances made in FY 01 was the development of common metrics to define the dectectability of various communications waveforms and the development of analytical techniques to compare the relative performance of these waveforms on a common basis. The previous comparisons to MOS signaling provide a useful baseline, but the implementation complexity of MOS is such that other modulations are generally used in commercial modems. In FY 01, we developed the analytical tools to compare CCSK and Code Division Multiplexing (CDMA), the primary modulation used in third-generation cellular telephones. Techniques to compare performance with CCK and other techniques used in commercial wireless local-area-network (WLAN) modems is in progress.

Another significant result in FY 01 was a proof that for the low values of signal-to-noise ratio (SNR) used in LPD applications, there is negligible difference in performance between a variety of methods that can be used to generate the modulation sequence. Comparisons of maximal length sequences (MLS), modified maximal length sequences (MMLS), and random sequences (RS) reveal that although MLS gives significantly improved performance at high SNR due to the improved peak-to-sidelobe ratio of the autocorrelation function, the results are insignificant at low SNR. This result is significant for LPD applications because the set of maximal length sequences is relatively small and the transmitter can potentially be intercepted by an exhaustive search over the limited number of MLS values. It was further shown that performance could be improved in some cases by using Gray codes to minimize the number of bit errors caused by timing or synchronization errors. However, there will be significant differences in performance at the higher SNRs needed for high-data-rate communications, and the comparative performance of various types of sequences is currently being evaluated.

To quantify the vulnerability of a given waveform, it is necessary to define a performance metric that is standard for the range of waveforms considered. The baseline metric selected is the radiometer, and it was shown that CCSK and M-ary Frequency Shift Keying (MFSK) have equivalent vulnerability to a radiometer detector. It was further shown that MFSK is considerably more vulnerable to detection by a channelized receiver. The channelized receiver consists of a bank of bandpass filters with each filter followed by an energy detector.

Another major result in this effort was the development of nonlinear adaptive signal-processing techniques to mitigate hostile interference with minimal distortion of the communications signals. It has been proven that the nonlinear effects can be used to significantly improve performance. This work is being done in conjunction with the University of California, San Diego (UCSD) and Professor Beex, a Professor from Virginia Tech and a Senior Research Associate of the National Research Council who is currently working at SSC San Diego.

The use of both space and time diversity is important both to high-data-rate and LPD systems. The publications on the Intersil Web site discuss the importance of antenna diversity to mitigate intersymbol interference (ISI) in high-data-rate modems. For LPD systems, the antenna diversity is important both for ISI and for minimizing the energy transmitted to hostile interceptors. This topic is being investigated in conjunction with UCSD and Professor Beex. Methods to adapt the weights of the antenna to maximize the power delivered to the receiver have been developed.

Work was initiated on the modification of CCSK to provide higher data rates and robustness in multipath. These issues are critical in the comparison with other modulation techniques under consideration for commercial standards. Multipath sensitivity is the key issue raised by Intersil relative to incorporation of CCSK into the commercial standards. In addition, comparisons to the commercial CDMA standards for cellular telephones and OFDM were also initiated. One of the properties of CCSK is that it is not efficient in its use of bandwidth since it requires that the bandwidth be doubled in order to increase the number of bits-per-symbol by one. This property is desirable for LPD because it spreads the energy over frequency and maintains the same detectability margin. However, this characteristic is undesirable for commercial applications because bandwidth is expensive. CDMA also requires more bandwidth to provide increased data rates. The goal of our CCSK/CDMA comparisons is to provide a thorough understanding of the tradeoffs in data rate and detectability between the two waveforms.

Acoustic Modeling in the Littoral Regime

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The propagation of high-frequency (8- to 16-kHz) acoustic communications signals in shallow-water environments is adversely affected by multipath propagation and the inhomogeneous and nonstationary nature of these environments. Multipath spread (caused by reflections and scattering from inhomogeneities) and Doppler spread (caused by the motion of these reflectors and scatterers) can significantly disperse and distort the signal as it propagates through the channel. The objective of this project is to develop a physics-based numerical propagation model that simulates these phenomena and facilitates investigation of their effects on communications performance. The output of the quadrature detector (QD) in a time-variant, doubly dispersive, shallow-water channel is modeled using three-dimensional Gaussian beam tracing, which accounts for out-of-plane reflections from rough surfaces or sloping bathymetry. Closely spaced microbeams of a finite-duration, constant-wavelength pulse are traced, in three-dimensions, from source to receiver, accumulating travel-time, phase-shift, and Doppler-shift information for each beam. This information is used to construct the QD response for all beams, which are summed to yield the total QD response. The QD response for a short pulse length provides an estimate of the channel impulse response (IR). Model IRs for a real shallow-water environment are observed to agree well with measured IRs.

SUMMARY

Recent innovations in shallow-water undersea surveillance and exploration have necessitated the use of the underwater acoustic medium as the primary means of information exchange. Wireless communication between underwater stations separated in range by as much as 5 km with water depths as low as 10 m may be required. This task is complicated by the inherent spatiotemporal variability of this medium, and the complex nature of multipath arrival of energy for shallow-water environments [1]. Figure 1 illustrates some of the major processes that may affect underwater communications signals.

Multipath spread is caused by refraction governed by sound-speed profile, reflections from boundaries, and scattering from inhomogeneities. Doppler spread arises from source/receiver motion or the motion of the reflectors and scatterers. These phenomena can significantly disperse and distort the signal as it propagates through the channel. A numerical propagation model that simulates these effects is desired for the systematic study of these phenomena. Such a model would also be useful for environment-dependence assessment, performance prediction, and mission planning of communication systems.

A compelling example of how ocean-channel physics can affect underwater communications was provided in engineering tests for the Front-Resolving Observatory with Networked Telemetry (FRONT) oceanographic network. The oceanographic conditions in the area are both interesting and complicated as fresh-river runoff interacts with the tides to generate a persistent front. The sound-speed structure in this area can fluctuate between upward-refracting and downward-refracting

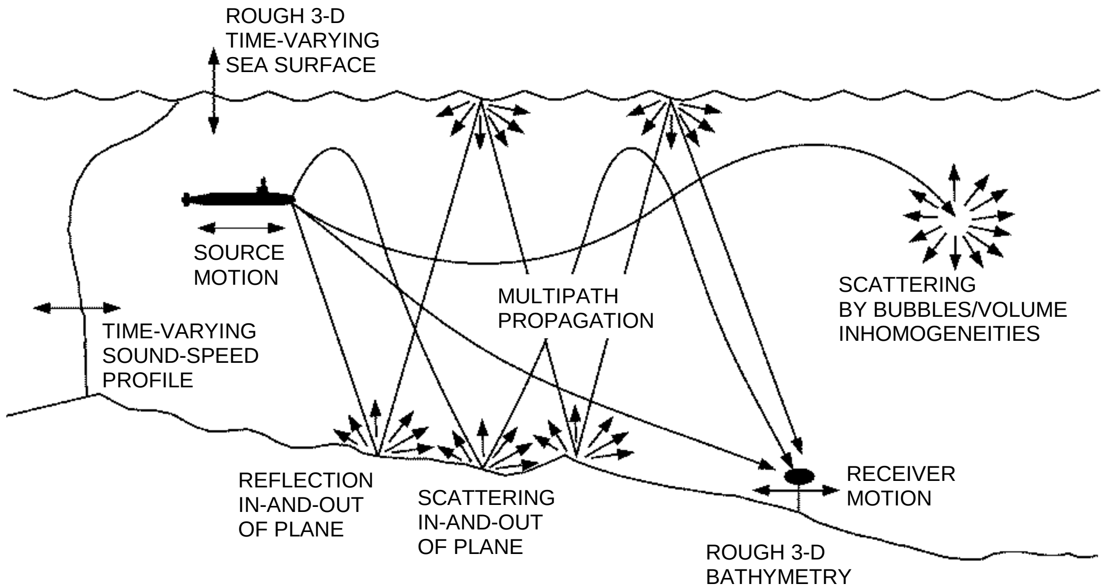

Figure 1. Important physical processes affecting underwater acoustic communications signals.

conditions over a short time period. During the course of the acoustic-modem deployment, there were periods with strong winds followed by relatively calm conditions. As the wind speed increased, wave action increased the ambient noise as well as the surface roughness, making it a poor acoustic reflector. The combination of these two factors decreased the signal-to-noise ratio (SNR) at a receiver, resulting in degraded modem performance as measured by the bit-error-rate. This is the simplest of mechanisms driving modem performance. Even with strong SNR, a modem that relies on a tap-delay line for adaptive equalization may fail if the multipath spread becomes too long. Similarly, a modem may fail to track Doppler changes, which is yet another dimension to the parameter space affecting modem performance.

CHANNEL MODEL

The objective of this project is to develop a physics-based numerical propagation model that (1) simulates multipath spread and Doppler spread of high-frequency underwater acoustic communication signals and (2) facilitates investigation of these effects on communications performance. Multipath spread is handled via propagation through a refractive medium, as dictated by the sound-speed profile, and by the modeling of reflection and scattering from arbitrarily rough boundaries. Doppler spread is incorporated via the inclusion of source/receiver motion and sea-surface motion. While other phenomena (water-mass fluctuations, scattering from water-volume inhomogeneities or bubbles) can be responsible for signal distortions, it is believed that those included are the primary sources of spreading for many realistic problems.

The basic approach is to model the received output of the quadrature detector (QD) for a transmitted finite-duration constant-wavelength (CW) pulse. The QD is an analog version of the discrete Fourier transform and provides a convenient means of obtaining the complex Fourier coefficients as a function of time for a finite-duration CW pulse. Since finite-duration CW pulses are common signals in communication schemes, the modeling of such signals is appropriate. However, a broadband QD response (for multiple CW pulses of different frequencies) can also be used to obtain a band-limited impulse response via Fourier synthesis, which is useful for the study of any arbitrary pulse signature. The QD response for a short pulse length provides an estimate of the channel impulse response.

The pulse is propagated by means of three-dimensional (3-D) Gaussian beams. The consideration of propagation in three dimensions is important since energy can be reflected or scattered in and out of the vertical plane containing both the source and receiver. The high frequencies of communication signals dictate the use of ray-based models over the less efficient wave models or parabolic-equation approximations. Ray-based models also ensure proper handling of range-dependence and proper reflections from sloping boundaries. The only ray-based method practical for the 3-D problem is to use Gaussian beams, since the necessity of eigenray determination is eliminated. Ray theory without the use of Gaussian beams requires the determination of eigenrays (rays following paths connecting the source and receiver exactly), which is a formidable task in three dimensions. The use of a dense fan of Gaussian microbeams allows direct modeling of scattering from arbitrarily rough surfaces.

The model has been successfully used to predict multipath spread, thus aiding in the design of recent experimental configurations for telesonar applications. Sublink 2000, conducted in 200-m water near San Diego, demonstrated real-time digital acoustic communications among a submerged submarine, a surface ship, bottom-mounted instrumentation packages, and gateway communication buoys. The feasibility of delivering data from commercial oceanographic sensors to shore was demonstrated in Seaweb 2000, conducted in roughly 10-m water in Buzzards Bay, MA. Another undersea network was deployed during the FRONT experiments, with the objective of delivering current profile data for the study of oceanfronts on the inner continental shelf (20- to 60-m water depth, near Long Island Sound). The SignalEx 2000 experiments were conducted in conjunction with the above experiments, and the objective was to correlate acoustic signaling performance with channel characteristics. For all of these experiments, the 3-D Gaussian Beam QD model predictions were used to determine optimal source/receiver configurations and to ascertain when the effects of a rough sea surface or variable bathymetry could degrade performance. In most cases, simulated impulses responses agreed well with measured impulses responses, although loss assumptions had to be adjusted because of inadequate knowledge of bottom properties.

GAUSSIAN BEAM TRACING

Gaussian beam tracing is a ray-based method of acoustic wave propagation that overcomes some of the implementation problems of conventional ray methods. By approximating a given source by a fan of Gaussian beams that propagate through the medium according to the standard ray equations, the field, at any given point, can be constructed by adding the contribution from each beam at that point. Eigenray computations, perfect shadows, and infinite caustics associated with standard ray methods are thereby eliminated, and the applicability to lower frequency problems is improved.

There are four approaches to the Gaussian-beam-tracing method currently applied to the ocean acoustics problem. While superficially similar, the approaches differ mainly in the type of beam distribution used (Gaussian or triangle) and the manner in which beam spreading is handled. The most rigorous method is that of Porter and Bucker [3], which is based on the seismological work of Cerveny et al. [4]. Gaussian beam spreading is governed by a pair of differential equations that are integrated along with the standard ray equations. Bucker [5] provides a simpler approach, termed

Simple Gaussian Beams (SGB), in which the beam width expands in proportion to the arc length of the beam path. Porter [6] later used the beam construct to develop Geometric Beam Tracing (GBT), which uses the Cerveny beam equations to calculate the spreading of the ray tube. GBT replaces the Gaussian distribution with a triangle function, with the beam influence decreasing from its maximum at the center ray to zero at the adjacent rays. The result is a model that precisely recovers the ray-theoretic result. Weinberg and Keenan [7] introduced the similar concept of Gaussian Ray Bundles (GRB), but with an additional feature that limits the beam focusing such that simple caustics are handled accurately. Without these limits, GBT and GRB are essentially the same, except for beam distribution used. Both the SGB and Cerveny methods require certain parameters to be set (e.g., the starting conditions of the beams) to run the models. The GBT and GRB approaches do not require such parameters and thus are more advantageous.

The merits and drawbacks of each approach were examined by casting each technique within the same theoretical framework and by comparing predictions with each other and a reference solution (normal modes) for several test environments, including the Sublink 2000 site. All algorithms agreed well enough with the reference solution to warrant their use in practical applications. The GBT and GRB methods possess the important advantage of not requiring certain parameters to be set before execution. The beam-focusing limits with the GRB method provide useful means of handling caustics.

ROUGH-SURFACE SCATTERING AND SEA-SURFACE MOTION

Scattering from rough boundaries produces losses in signal energy. These losses are two-fold. First, scatter converts energy to higher angles, eventually allowing the signal energy to penetrate the bottom where it is absorbed. Second, scatter destroys the coherence of the wave, thereby producing what might be termed an apparent loss. For instance, a moving surface will stretch and compress a sinewave reflected from it. If the reflected energy is detected by a matched-filter expecting a perfect sinewave, the matched filter will see a reduced power level. This discussion applies, for instance, to a single tone in an M-ary Frequency-Shift Keying (MFSK) signaling scheme, where a filter bank detects the tone. If we have a rough bottom with a static geometry, this loss of coherence does not occur. However, if the source or receiver moves, we have a dynamic situation similar to the surface loss just described.

In round numbers, a typical communications carrier gives a wavelength of approximately 10 cm. A classical measure of the role of roughness—the Rayleigh roughness parameter—is the ratio of the roughness to the wavelength (or more precisely, the vertical component of the wavelength). As this number becomes close to unity, losses per bounce become large, perhaps 10 dB, and many of the standard scatter models that assume small roughness fail. The point of this discussion is that 10-cm roughness is easily attained on both surface and bottom boundaries in real environments, implying large boundary losses. Furthermore, the roughness is typically not known to within 10 cm, implying large uncertainty in those same losses and in the resulting transmission loss.

Finally, the actual scatter mechanisms are complicated. In some cases, the air–water interface is the scatterer. In other cases, the bubbles below are likely to be dominant. Similarly, at the ocean bottom, scatter can occur at the interface or by inhomogeneities just below the interface (though not too far below since volume attenuation limits the sediment penetration significantly).

As a first step toward modeling scattering effects, we assumed that the boundary roughness dominates the problem, and we concentrated first on the bottom roughness. A common approach [8] to characterize this roughness is to use the spatial power spectral density, i.e., the power spectrum of the bottom roughness. Various forms may be used; however, one popular choice is $\Phi(k) \propto k^{-b}$, where b is a measured parameter for the particular site. Suggested values for b are given in [8] along with the root mean square (RMS) roughness that defines the overall amplitude of the spectrum.

Given the spatial power spectral density, individual realizations of the bottom can be constructed using a standard technique. In particular, the power spectrum is converted to an amplitude spectrum by taking its square root. The amplitude is then discretely sampled, and a random phase is introduced. Finally, a Fast Fourier Transform (FFT) is performed, and the mean depth is added to obtain a single realization of the bottom. In equations therefore,

$$D(r) = \int A(k) e^{\theta} e^{ikr} dk$$

where $A(k) = \sqrt{\Phi(k)}$ and $\Phi(k) = 5.5 \times 10^{-5} k^{-2.25}$ is the spatial power density spectrum for a particular area.

The effects of a time-varying sea surface are modeled by constructing realizations of the time-dependent sea-surface based on realistic sea-surface wave spectra. As a beam interacts with the sea surface, a Doppler shift is imparted to the beam, which is then included in the calculation of the QD response for that beam. The total Doppler spread of the signal can then be determined upon summations of the QD responses for each beam to obtain the total QD response.

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High-Linearity Broadband Fiber-Optic Link Using Electroabsorption Modulators with a Novel Dual-Wavelength, Second-Harmonic Cancellation Scheme

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Electroabsorption (EA) modulators have been developed for use in demonstrating a highly linear, broadband fiber-optic link. The EA modulator has a bias point that inherently nulls third-order distortion and provides highly linear analog transmission over a suboctave bandwidth. To suppress the modulator's second-order distortion for multi-octave transmission, we propose a push-pull link architecture where complementary (inverted and noninverted) signals are used to drive two EA modulators. The signal is recovered through differential photo-detection. The dual-wavelength link provides nearly distortion-free signal transmission. Extremely linear, broadband links are needed for applications such as shipboard antenna remoting, radio frequency (RF) distribution, and control of active phased-array antenna signals. This demonstration is based on a prior patented technique (Navy Case 79042).

SUMMARY

To demonstrate a broadband, high-linearity fiber-optic link for Navy shipboard applications, we developed an efficient electroabsorption (EA) modulator with good linearity. A novel dual-wavelength transmission link for even harmonics cancellation will be used to further enhance the link linearity.

BACKGROUND

The military's network-centric warfare vision is challenging network and system architects to fully use available channel bandwidth. For intra-platform information exchange, this requirement translates into maximizing the analog/digital data flow through a single channel. The tremendous bandwidth capabilities of optical fibers make them the transmission medium of choice for next-generation military local-area networks (LANs) and antenna networks. However, the linearity of the photonic links must be improved to fully take advantage of the available bandwidth. Broadband analog or mixed-signal photonic links with improved linearity are required for shipboard antenna remoting as well as radio-frequency (RF) distribution and control of active phased-array antenna signals. Size, weight, and electromagnetic interference (EMI) immunity are additional advantages of using fiber-optic technology. These are also critical topside design-engineering issues. The photonic link envisioned for future shipboard (e.g., DD 21 and CVX) applications requires transmitting a combination of communication, radar, and electronic warfare signals over a single fiber. Due to the span of the signal spectrum, a broadband link is required. Present single EA modulator links operating at a third harmonic null can deliver signals over suboctave bandwidths with low third-order harmonic distortions, but such use for multi-octave transmission is limited by the modulator's second-order harmonic distortion.

Dr. C. K. Sun and Dr. Steve Pappert at SSC San Diego have invented a dual-wavelength link transmission scheme to suppress second-harmonic distortion generated by the modulator. This dual-wavelength transmission scheme is particularly beneficial for suppressing the second-harmonic distortion generated by the EA modulator, thus enabling the possibility of using EA modulators for broadband transmission with improved linearity. To demonstrate this novel concept, efficient EA modulators working at two slightly different wavelengths are required. For this linearization approach to be successful, low optical insertion loss and high RF efficiency are essential modulator requirements.

APPROACH

To improve the performance of the EA modulator, it would be necessary to modify semiconductor material and device structure design and to improve the fabrication process. High-quality epitaxial (epi) materials with different bandgap energies were acquired from the University of California, San Diego (UCSD) and tailored for low-optical propagation losses at selected laser wavelengths. A large optical-cavity waveguide design was used to lower the fiber-to-fiber optical coupling loss. The electrode design was also changed from ground-signal-ground to signal-ground to reduce the length of the cleaved modulator. Fabrication process improvement reduced the waveguide scattering loss caused by surface roughness associated with the wet chemical etching process.

The novel dual-wavelength linearization scheme uses two modulators, operating at two slightly different wavelengths. The RF signals applied to the two modulators are 180° out of phase. The optical signals are combined through a wavelength-division-multiplexing (WDM) coupler, transmitted through a single fiber, de-multiplexed through a WDM coupler, then detected by a balanced photodetector that combines two RF signals with one signal 180° phase-inverted. This transmission scheme can eliminate even-order harmonic distortions in the link due to push-pull operation, similar to a class AB amplifier.

RESULTS

The FY 01 goal was to design and fabricate an EA modulator suitable for push-pull operation in the dual-wavelength link. The Navy and UCSD have jointly designed and fabricated EA modulators with a large optical cavity, operating in the 1550-nm wavelength range. The modulator was characterized with RF network analyzer measurements. These measurements demonstrate that the modulator has a diode capacitance of 180 fF and a 3-dB modulation bandwidth of 5 GHz. Modulators with 20-GHz bandwidth are being pursued. The optical insertion loss of these devices ranged from 11 dB to 13 dB over the wavelengths of interest (from 1540 nm to 1570 nm for a modulator with an active region bandgap wavelength λ_{bg} = 1460 nm). This result was a significant improvement over the previous year’s best effort of 18-dB insertion loss.

Simulations were performed to determine the optimized operating wavelengths. The simulations narrowed the parameter space that needed to be explored experimentally. The optimized wavelength is referenced to the detuning between the modulator’s bandgap energy and the shorter laser wavelength ($\lambda_{bg} - \lambda_1$) and the optimized wavelength spacing ($\lambda_1 - \lambda_2$) for linearizing the link. Simulations that use a physics-based model of the EA coefficient in the modulator reveal that the second-harmonic suppression degrades as a function of wavelength spacing (Figure 1). Maintaining greater than 30-dB suppression of the even-order distortion will require a wavelength spacing less than 3 nm. Conveniently, for a given wavelength separation, the detuning energy has little bearing on the distortion suppression (see Figure 2). This insensitivity is further supported by simulations demonstrating that the magnitude of the second harmonic as well as the modulation efficiency are only slightly degraded with increasing

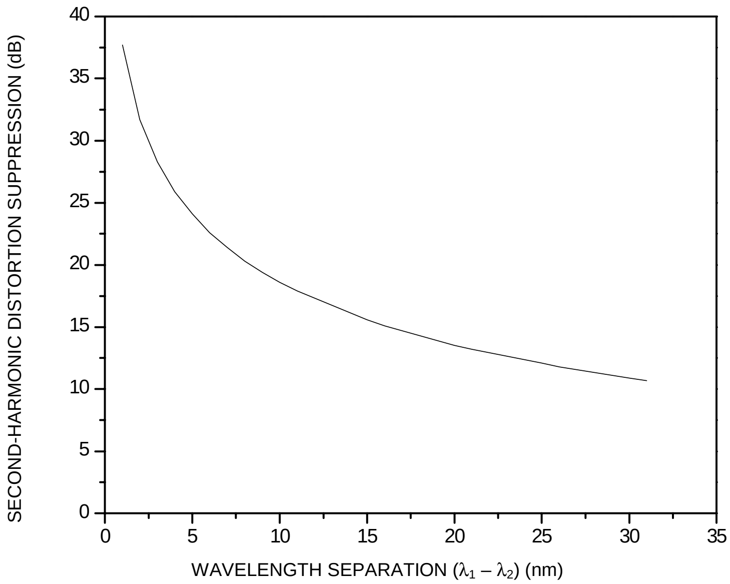

Figure 1. Simulated second-harmonic distortion suppression in a dual-wavelength link as a function of the difference between the two wavelengths. For suppression greater than 30 dB, spacing less than 3 nm is needed.

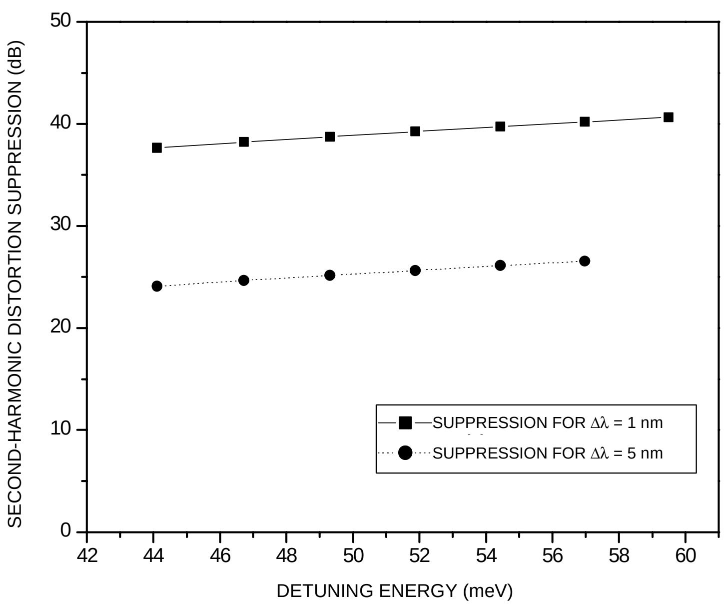

Figure 2. Simulated second-harmonic distortion as a function of the detuning energy: the difference between the shortest wavelength and the modulator's active-layer bandgap. The second-harmonic suppression is relatively insensitive to the detuning energy.

detuning energy. From these simulations, we conclude that optimized wavelengths have approximately 50-meV detuning and less than 3-nm wavelength separation. We also note that using larger wavelength spacing will necessitate using in-line attenuators after the modulators to fine-tune the second-harmonic distortion from each modulator in order to achieve maximum distortion suppression at the balanced detector.

The harmonic distortion of single modulators was experimentally characterized and compared to simulations. Figure 3a shows a typical second harmonic resulting from a single sinusoidal tone input at 910 MHz. Comparisons show that the simulation is a fair predictor of the harmonic distortion despite the apparent dissimilarity of the measured relationship between the unmodulated intensity and the static voltage bias. The simulation is an adequate predictor of the voltage bias point (within 200 mV) at which there is a nulling of the second- or third-order harmonic distortion (Figure 3b). The magnitude of the distortion is inadequately predicted by the simulation. Measured distortion values are within 5 to 15 dB of the simulation results. The qualitative conclusions of the simulations in regard to distortion as a function of wavelength are well supported by these measurements.

The demonstration of the complete dual-wavelength link will be completed in FY 02. Extensive characterization of the linearity of the link will be performed, and the limitations and tolerance of this distortion cancellation scheme will be quantified.

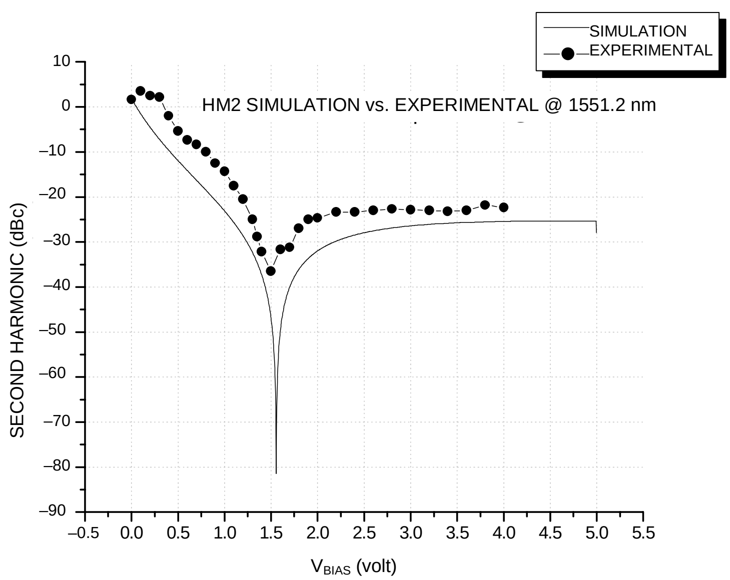

Figure 3a. Comparison of calculated second-harmonic distortion with experimental results as a function of modulator voltage for an RF input of +4 dBm. The one-tone test was performed on a single modulator.

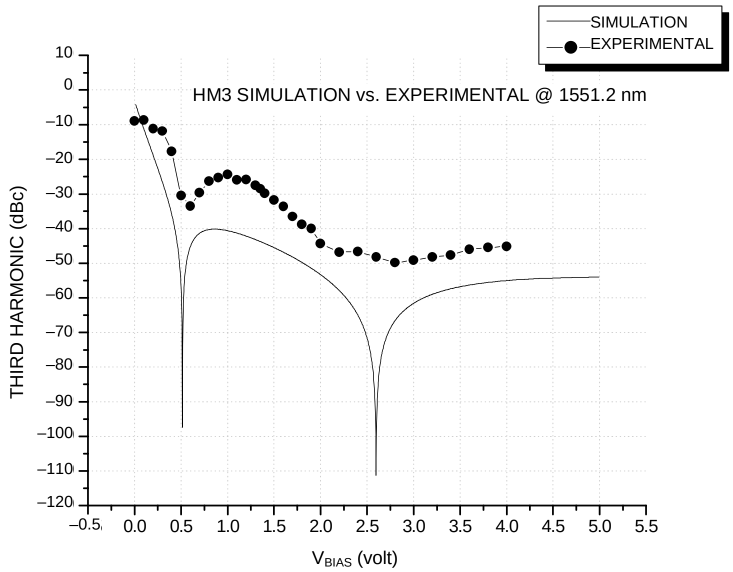

Figure 3b. Comparison of calculated third-harmonic distortion with experimental results as a function of modulator voltage for an RF input of +4 dBm. The one-tone test was performed on a single modulator.

Intelligence, Surveillance, and Reconnaissance

CRANOF: A Complexity-Reducing Algorithm for Near-Optimal Fusion with Direct Applications to Integration of Attribute and Kinematic Information

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Our overall goal is to develop a general algorithm that is mathematically sound and computationally efficient for processing probabilistic or linguistic information that may be incomplete, uncertain, or ambiguous. Such an algorithm must use as inputs **both** ***the available probability evaluations of the events under consideration and the underlying logical relations among those events. The outputs of this algorithm are quantitatively or qualitatively expressed probabilities that can be used directly in data fusion, intelligence analyses, computer simulation of intelligent military opponents, user–system interface design, and decision-making in general. During FY 01, major advances toward these goals were obtained through use of (a) a novel second-order Bayesian approach and (b) a tradeoff between optimality of results and computational complexity. One significant result achieved during FY 01 was a breakthrough establishing a new, mathematically sound, and feasible-to-implement method of trading off a slight decrease in solution optimality for a large increase in computational efficiency. Another significant result was a solution of the problem of reasoning with rules having low exception rates when no assumptions are made concerning the relative magnitudes of those exception rates. Applications of our results were also made to the problems of track fusion and detecting cyber intrusions in computer networks.***

SUMMARY

In different arenas such as sensor fusion, intelligence analyses, decision support, computer wargaming, and user–system interface design, the Navy has a need to integrate disparate types of data that may be incomplete, uncertain, or ambiguous. The goal of our project is to develop a new method of integrating disparate and uncertain information. Our method must be mathematically sound, computationally efficient, and compatible with commonsense reasoning.

Rather than discuss the many potential applications of our project, we will concentrate on multisensor fusion. Sensor-fusion algorithms (e.g., the integration of over-the-horizon radar track data with microwave radar track data) rely increasingly on automatic, rule-based systems that incorporate both kinematic and attribute data. In today's information-rich, highly connected computing environments, there has been little investigation of the performance characteristics of combining information derived from multiple heterogeneous sensors tracking multiple targets. Also, leading researchers in sensor-fusion and tracking theory (Hall [1992], Waltz & Llinas [1990], Blackman [1986], Blackman & Popole, [1999], and Drummond [1998]) agree that it has not been possible to design truly optimal algorithms for sensor fusion due to the immature development of critical needs. Significant progress has been made in several fields that contribute to our understanding of the data-fusion problem, including probability theory, Dempster–Shafer theory, fuzzy logic, rule-based systems, reasoning procedures, and heuristics. The co-investigators of this project (Bamber and Goodman), the associate investigator (Torrez), the university collaborator (Nguyen), as well as other researchers, have been among those active in developing mathematical techniques useful for constructing sensor-fusion algorithms. See, for example, Dillard (1983, 1992) for utilization of Dempster–Shafer theory; Torrez & Yssel (1999) and Torrez & Blasch (2000), for applications of a variety of data-fusion techniques; Goodman, Mahler, & Nguyen's 1997 text on theory and use of specialized procedures—especially random sets and conditional event algebra—to enhance sensor fusion; Goodman & Kramer (1997) also on use of random set theory, and Calabrese (1987) and Goodman & Nguyen (1995) on conditional-event algebra foundations; Goodman & Nguyen (1999b) on the integration of conditional-event algebra and fuzzy-logic concepts and related topics; Nguyen & Walker's text (2000) on the development and use of fuzzy logic; Bamber (1994, 1998, 2000), Goodman (1999), Bamber, Goodman, & Nguyen (2001), Adams (1996), and Pearl (1988, 2000) on theory and application of probabilistic reasoning systems. However, it is clear that (a) the issues of computational simplification and rule selection, as well as the design of inference rules compatible with the above information-processing techniques, have also not been adequately treated, despite significant progress in computational complexity theory, as documented in Papadimitriou (1994); and (b) there has been no *unified* approach that is both mathematically sound and compatible with commonsense reasoning, for integrating the above fields for use in sensor fusion.

In response to such circumstances, this project addresses (1) choice of reasoning system and (2) rule-design issues. While the project, at present, is centered on problem (1), it will also treat problem (2).

(1) *Choice of reasoning system*. Substantial progress had already been made prior to the beginning of this project via the use of second-order probability reasoning. Specifically, it was shown that a logical system should have as many desirable features as possible, such as *contraposition*, *weighting*, *induction*, and *chaining*, without violating consistency (see, e.g., Pearl, 1988). Among the most important features is conclusion chaining, whereby the output of one rule becomes the input of another. This property certainly holds true in a classical logic setting where no input/output errors are present; however, in reflecting the uncertainty of the real world, inference rules are generally reliable, but not completely error-free. There exist rules and choices of probabilities measuring the usual reliability of those rules via conditional probabilities, so that contrary to commonsense, chaining appears to fail. This has led to a 30-year controversy. However, the co-investigators have shown (see, e.g., the recent papers: Bamber, 2000; Goodman, 1999; Goodman & Nguyen, 1998–2000; Bamber, Goodman & Nguyen, 2001) that a mathematically sound, commonsense—and, in many cases, implementable—procedure exists that satisfactorily addresses not only the above problem of chaining, but a whole host of others. In reality, no actual discrepancy exists between probability calculations involving the inference rules in question and commonsense reasoning. This is because such problems can be resolved by adopting a second-order probability viewpoint, that is, by taking into account uncertainty about the probabilities themselves.

(2) *Rule-design issues*. There appears to be no current rationale for deciding what aspect of a given problem is to be based on a rule-based system and what aspect is to be based on other techniques. In fact, this problem includes the issue of whether to use only inference rules (as an intermediate step in utilizing the given information) or to make direct use of the given (training) information via standard regression analysis techniques. In turn, this problem involves choosing an inference-rule system with either many rules (where each rule is relatively simple in form) or choosing a system with only a few rules where each is relatively complex.

APPROACH

All of the above reasoning issues may be treated via a Bayesian second-order probability approach called Complexity-Reducing Algorithm for Near-Optimal Fusion (CRANOF) that explicitly takes into account the problem of reducing the complexity of computations. In brief, the general CRANOF algorithm addresses problems of reasoning involving uncertain or incompletely specified probabilities. That is, there is a given set of either known or lower-bounded probabilities and a set of designated events of interest whose probabilities are not uniquely determined, but are desired (as in the chaining problem). When the desired probabilities are uniquely determined, CRANOF will find their values; but when they are not uniquely determined, CRANOF finds their *most central* value. In general, CRANOF can be applied to a wider variety of probability problems than exact-knowledge techniques, which, as in the case of Bayes nets (see Pearl, 1988), typically make a large number of independence assumptions in order to guarantee uniqueness. Consequently, CRANOF is able to deal with problems involving not only uncertain information, but also underdetermined information, which frequently occurs in sensor-fusion problems. Yet, as discussed above, there remain the overriding issues of rule reduction, modification, and selection, all of which are critical to achieving computationally tractable sensor fusion.

The structure of the CRANOF algorithm is based on the synthesis of three previous major achievements concerning rule selection and reduction (Bamber & Goodman, 2000):

Achievement 1. Under a (somewhat restrictive) consistency assumption, any finite set of inference rules whose associated conditional probabilities are all reasonably high may be reduced to a near-equivalent single rule. This assumption means that the single rule (for reasonably high validity thresholds) asymptotically yields essentially the same CRANOF estimators of conclusion validity as if the entire set of inference rules were used. While this rule is more complex in form than each of the original rules, its total complexity—and that associated with its subsequent use in the conclusion validity estimation phase—is significantly less than if the original set of rules had been used. In CRANOF, this extreme reduction has actually been shown (as of the end of FY 01) to be modifiable by replacing the original rule set by a relatively *small* set of rules, not necessarily a single rule—see new results for FY 01 below.

Achievement 2. A simple substitution procedure can be used, analogous to that employed by the standard maximum entropy approach, but unlike the latter (see, e.g., Rödder & Meyer [1996] and Rödder [2000] for an exposition of both an efficient algorithm for computing recursively maximum entropy estimators and developing an associated logic), a *relatively simple closed-form* expression can be obtained. (During FY 01, Achievement 2 has also been significantly extended—see next section on FY 01 results and also Goodman, Bamber, and Nguyen, to be submitted.)

Achievement 3. Via a fundamental (but often overlooked) theorem of regression theory (Rao, 1973), the direct use of training information extracted from a given database provides an alternative to the use of a rule base extracted from the same database. In future work, CRANOF will also extend Achievements 2 and 3 so that with Achievement 1, a viable rule selection and reduction procedure will exist for large classes of rule-based systems, including those pertaining to all levels of sensor fusion.

Also, the actual implementation of CRANOF consists of two aspects: (1) rule reduction, modification, and selection; and (2) application of the near-optimal reasoning system to data association and sensor fusion for tracking. Aspect (1) is a direct extension and integration of the three major achievements mentioned previously. Aspect (2) produces outputs that can be considered optimal or "near-optimal" estimates of candidate conclusion validities, with inputs being probabilistic or linguistic, conditional or unconditional (or factual) in nature. This method allows for potentially including a full decision-theoretic (i.e., utility/cost function) structure based on incompletely specified probabilities, as well as linguistic and causal information. More generally, CRANOF is capable of operating as a general decision support system relevant to sensor fusion operating on both uncertain and under-specified information. Finally, the reasoning aspect of CRANOF can be directly applied to correlation/ association and fusion of geodynamical tracking information with attribute information.

FY 01 RESULTS

We documented our FY 01 work in the following papers: Bamber & Goodman (2001c); Bamber, Goodman, & Nguyen (2001); Bamber, Goodman, & Nguyen (submitted for publication); Bamber, Goodman, Torrez, & Nguyen (2001); Goodman (2001); Goodman & Bamber (to be submitted); Goodman, Bamber, & Nguyen (to be submitted); Goodman & Kreinovich (2001); Goodman, Trejo, Kreinovich, Martinez, & Gonzalez (2001); Torrez, Bamber, & Goodman (2001); Torrez, Goodman, Bamber, & Nguyen (2001). In addition, we gave the following unpublished oral presentations: Bamber & Goodman (2001a, 2001b); Goodman & Bamber (2001).

Our FY 01 results can be categorized as solutions together with applications to two types of problems: (a) exact threshold problems where specified values of the probability thresholds, which may be anywhere in the zero-one interval, are given and (b) near-unity threshold problems where all that is known about the relevant rule probabilities is that they are close to one. The new results obtained during FY 01 include the following items: (1) We obtained an unexpected major result concerning exact threshold problems in that a new method was developed of trading off optimality vs. complexity by using results from the near-one threshold problem as a guide. A key aspect of this mathematically rigorous result is that the unnecessarily restrictive consistency assumption mentioned in Achievement (1) can be dropped and the reduction of rules can be to a small set of relatively non-complex inference rules. Using a Bayesian prior Dirichlet distribution for the second-order probabilities, a complete closed-form expression can be obtained for both the exact and near-one threshold behavior of the entire system. (2) Another major result was the solution of the near-unity threshold problem under the weakest possible assumptions, namely, when no assumptions are made concerning the relative magnitudes (across rules) of the various rule thresholds' distances from one. Specifically, it was shown that there are various equivalent methods of testing whether a conclusion is inferable from a collection of rules that are employed as premises. One such method involves checking whether a particular directed graph (that represents the premise rules) has a certain property (that represents the conclusion). Another such method involves showing, first, that there exists an "argument" that supports the conclusion and, second, that every "counterargument" that supports the negation of the conclusion is "overridden" by some argument that supports the conclusion itself. Applications of our results were also made to the problems of track fusion and detecting cyber intrusions in computer networks, Bamber, Goodman, Torrez, & Nguyen (2001); Torrez, Bamber, &

Goodman (2001); Torrez, Goodman, Bamber, & Nguyen (2001), as well as logic and general reasoning, Goodman & Kreinovich (2001); Goodman, Trejo, Kreinovich, Martinez, & Gonzalez (2001).

Making use of the two major results of FY 01, the CRANOF algorithm will be expanded in FY 02 to include, in an integrated manner, the solutions of both the exact threshold and near-unity threshold problems. This will enable a full software implementation of CRANOF for the fixed threshold case, once a number of crucial research issues have been solved in FY 02, including reduction of sub-looping among Boolean operators and recursive integration of updated information. Furthermore, preliminary results that were obtained during FY 01 on problems involving linguistically expressed probabilities will be extended during FY 02.

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Modeling of Acoustic Radiation in the Time Domain with Applications to Nonlinear Structural-Acoustic Interaction Problems

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Code 2711, (619) 553–2018

This project seeks to maintain a state-of-the art modeling capability for underwater electro-acoustic transducers and to contribute to the general knowledge base for underwater acoustics and structural-acoustic interaction. The specific objective is to produce a time-domain, boundary element, acoustic radiation computer program. This program should be capable of modeling structural acoustic radiation into a surrounding fluid and should use time-domain computations based on the Kirchhoff integral equation.

BACKGROUND

The usual way to model structural-fluid acoustics is in the frequency domain. This method is excellent for linear problems. However, the Navy is developing high-power active materials that can be driven beyond their range of linear response. To model transducers using these materials requires a nonlinear structural model and produces a time-domain response for the radiating surface. There is a need for a corresponding time-domain code to model the acoustic radiation in the fluid.

WORK COMPLETED

We have implemented the Kirchhoff equation in a computer program using boundary elements. This code resembles the Navy's frequency domain program CHIEF, which has been used by government laboratories and contractors for many years. The new code was developed by using some existing CHIEF code for the structure's geometry. We tested the new code on several problems for which answers could be computed by alternate means and, in this process, made several refinements. The code seems to work very well for most time-domain modeling problems. However, we did observe the same numerical difficulties with this algorithm that have been reported in the past.

These difficulties led to a number of computational experiments, and some theoretical analysis was performed to understand and explain these problems. We found that the Kirchhoff equation, without any numerical approximations, has some very poor solutions. These solutions have qualities such as very delicate stability that are difficult or impossible for a numerical algorithm to control. So, as integration in time is performed, the problems may well spuriously appear and contaminate the desired, true solution. This problem is only troublesome for certain types of modeling tasks, such as calculating an impulse response.

These spurious solutions also cause the following effect: We observed in our numerical experiments a trade-off between the solution accuracy and its stability. For instance, a small time step leads to an accurate but somewhat unstable solution, and a large time step causes just the opposite effect. Good modeling requires the correct balance of numerical parameters.

To our knowledge, many of the results of this research have never been reported in the literature, and we expect to publish some of our findings. An SSC San Diego technical report detailing these results is in progress. This report will also form the basis for a refereed publication.

RESULTS

Figures 1 through 5 show surface pressures calculated using the new “Time-Domian CHIEF” program. These calculations are done for a spherical surface that is being uniformly accelerated over its surface. This scenario would represent an idealized underwater electro-acoustic transducer application, but it also gives us a physical model for which the true surface pressure can be calculated by hand.

The surface for all plots was accelerated from the rest by a sine wave in time that was turned off after half a period; this is of time length W=1 for the time scale shown. The plots of pressure compare the true analytic solution (solid line) with the Time-Domain CHIEF calculation (dotted line) for the boundary element at the north pole of the sphere. Error plots also show two curves: one is the difference of calculated and analytic at the pole, and the other is this difference for a CHIEF element at the equator. (The true, analytic pressure is, of course, uniform over the entire surface.) There were six CHIEF elements used in latitude and 12 used in longitude for the surface discretization in all plots shown.

Most of these plots depict the trade-off between time step size, $d\tau$, and the number of “points” (i.e., pressure values in time) used to estimate (or “smooth”) the time derivative of pressure. We found the use of smoothing for the numerical calculation of the derivative to be indispensable for stability. The higher the order of smoothing, the more stable but less accurate the surface pressure, as well. Similarly, larger time steps give better stability but less accuracy. In typical fashion for a numerical code, computational accuracy over a sustained time interval requires the proper balance of smoothing and time step size.

Note that the apparent periodicity in the error plots is no accident; the error structure reflects exactly those frequencies that are “irregular” in the frequency domain, i.e., those that give rise to non-zero solutions of the homogeneous Helmholtz integral equation. This issue will be more thoroughly addressed in the forthcoming technical report.

Figures 4 and 5 show a striking example of the difference that derivative smoothing can make. With three-point smoothing, the time calculation becomes severely unstable after approximately three to four normalized time units. Changing to five-point smoothing for the derivative allows for stable calculations for well over eight normalized time units.

With the lessons learned and the computer model now implemented, the transducer group at SSC San Diego now has a definite capability for modeling high-power projectors and has a basis from which to propose important Navy work on other nonlinear fluid-structure acoustic interaction problems.

ACKNOWLEDGMENT

Sincere thanks to Dr. George Benthien for his interest and help with the many numerical experiments that were done during this research. His dedication allowed a much more thorough testing of the Time-Domain CHIEF code than would have been possible to accomplish alone.

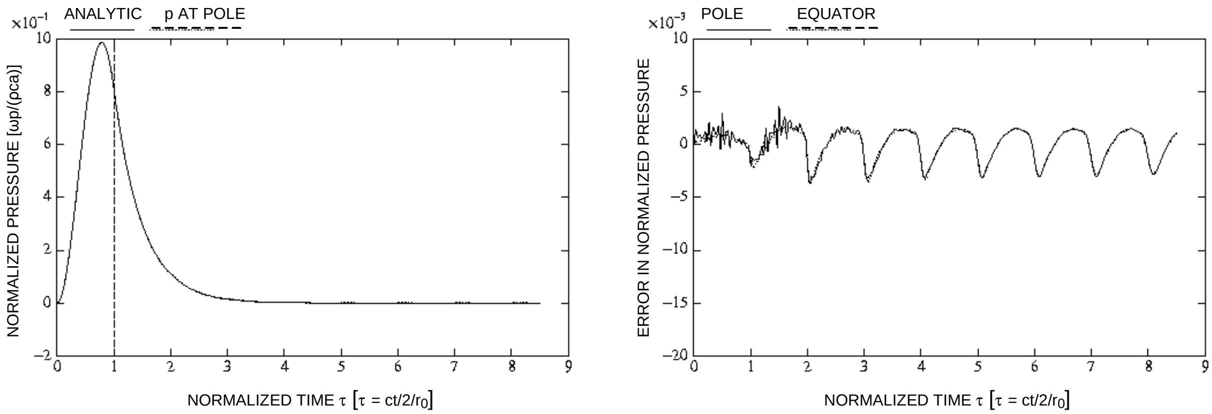

Figure 1. Pulsating sphere, W = 1.0, three-point smoothing, dτ = 1/30.

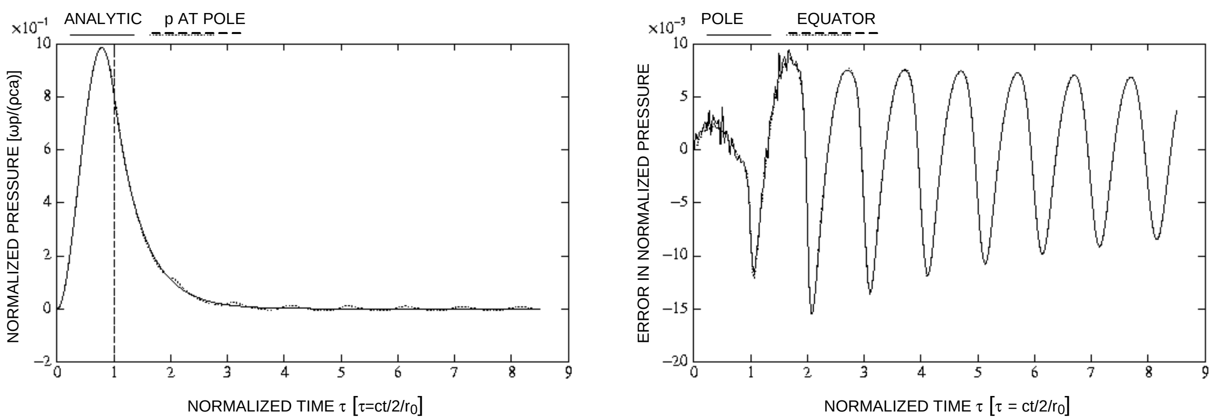

Figure 2. Pulsating sphere, W = 1.0, seven-point smoothing, dτ = 1/30.

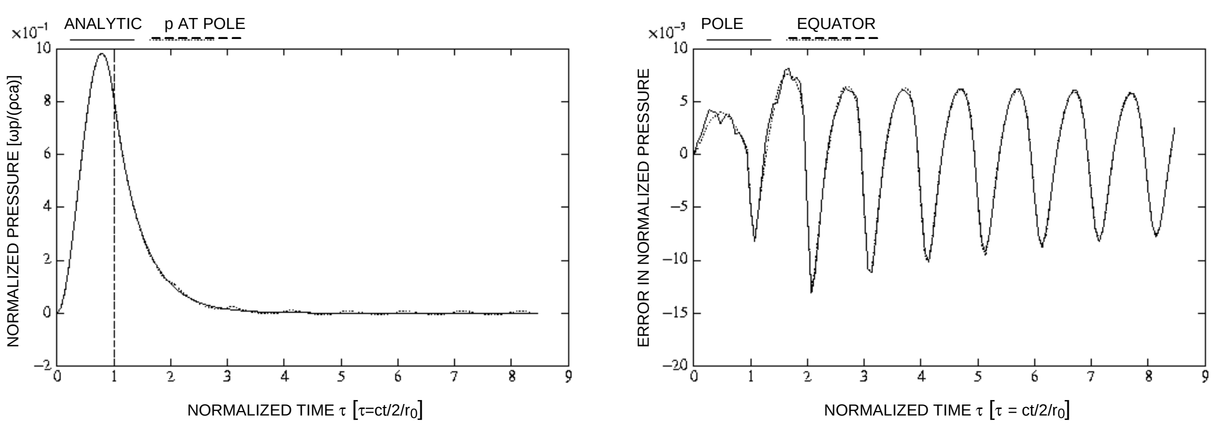

Figure 3. Pulsating sphere, W = 1.0, three-point smoothing, dτ = 1/15.

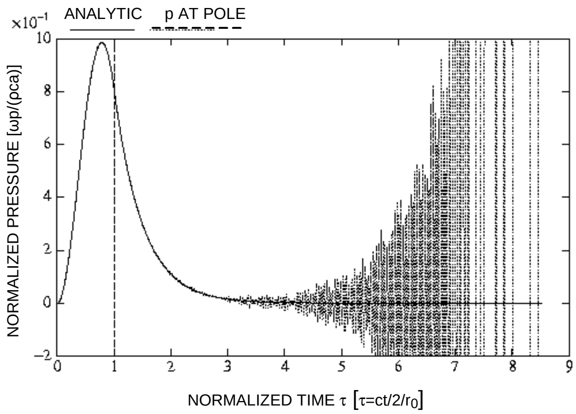

Figure 4. Pulsating sphere, W = 1.0, three-point smoothing, dτ = 1/90.

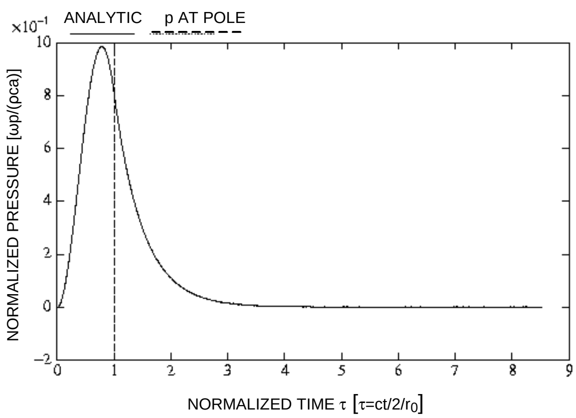

Figure 5. Pulsating sphere, W = 1.0, five-point smoothing, dτ = 1/90.

Hyperspectral Detection Processing Development

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Hyperspectral data are often modeled using either a linear mixture or a statistical classification approach. The linear mixture model describes each spectral vector as a constrained linear combination of end-member spectra, whereas the classification approach models each spectra as a realization of a random vector having one of several normal distributions. This work describes a stochastic compositional model that unifies these viewpoints by modeling each spectra as a constrained linear combination of normal vectors plus additive noise. Maximum likelihood methods of estimating the parameters of the model are derived, and anomaly and likelihood ratio detection statistics are obtained. The performance of anomaly and known-signal detection algorithms derived from the classification, linear mixing, and stochastic compositional models are compared using data consisting of ocean hyperspectral imagery to which the signature of a personal flotation device has been added at pixel fill fractions (PFF) of 5 and 10 %. The detection algorithms based on the stochastic compositional model reduced the number of false alarms by more than an order of magnitude in comparison with algorithms based on either a linear unmixing or a normal mixture model.

SUMMARY

Most work involving compositional data has assumed that the observations $y_i \in R^n$ are well represented by the linear mixture model:

$$y_i = \eta + \sum_{k=1}^{d} a_{ki}\varepsilon_k \quad \text{such that constraints c.1) } 0 \le a_{ki} \text{ and c.2) } \sum_{k=1}^{d} a_{ki} = 1 \tag{1}$$

where, d is the number of classes, $\varepsilon_k \in R^n$ is the signature or endmember of class *k*, a_{ki} is the abundance of class k in observation y_i, and $\eta \sim N(\mu_0, \Gamma_0)$ is an additive noise term with normal probability distribution function (pdf) of mean μ_0 and covariance Γ_0. In this model, variability of the observations arises from variability of the abundance values and additive noise.

Observations may also exhibit intraclass variability. If each observation arises from one of d normal classes, then the data have a normal mixture pdf:

$$p(y) = \sum_{k=1}^{d} \omega_k N(\mu_k, \Gamma_k)(y), \; \omega_k \ge 0, \; \sum_{k=1}^{d} \omega_k = 1, \tag{2}$$

where ω_k is the probability of class *k*. For many applications, data may consist of observations from pixels that are composed of multiple materials such that the observations from a given material have random variation. For such data, neither the linear mixture model nor the normal mixture model is adequate, and better classification and detection results may accrue from using more accurate methods.

Stocker and Schaum [1] propose a stochastic mixture model in which each fundamental class is identified with a normally distributed random variable, and observations y_i are modeled as a composition:

$$y_i = \sum_{k=1}^{d} a_{ki}\varepsilon_k \text{ such that } \varepsilon_k \sim N(\mu_k, \Gamma_k),\ a_{ki} \geq 0, \text{ and } \sum_{k=1}^{d} a_{ki} = 1. \quad (3)$$

To estimate parameters of the model, the allowed abundance values are quantized, e.g., $a_{ki} \in \{0, 0.1, \ldots, 0.9, 1\}$, and each combination of quantized abundance values that satisfies the constraints is associated with a normally distributed class having mean and covariance as the corresponding linear combination of the fundamental mean vectors and covarince matrices. The data are then fit to the normal mixture model consisting of these classes. Stocker and Schaum demonstrate improved classification and detection using this model with three fundamental classes [1]. This approach is limited to a small number of fundamental classes as the number of mixture classes grows very rapidly with the number of fundamental classes. Furthermore, the quantization of the abundance values limits the accuracy of the class parameter and abundance estimates.

OBJECTIVE

Our objective was to develop a model of compositional data that unifies the Gaussian mixture and linear mixture models and is applicable to data composed of a large number of classes. We also wanted to develop maximum likelihood estimators of the parameters of the model and to develop maximum likelihood classification, anomaly detection, and target detection algorithms for signals that are known within one or more dimensions. We would compare the performance of the detection algorithms derived from the model with comparable algorithms derived from the Gaussian mixture and linear mixture models.

RESULTS

1. Stochastic Compositional Model

The stochastic compositional model represents each observation $y_i \in R^n$ as

$$y_i = c\eta + \sum_{k=1}^{d} a_{ki}\varepsilon_k \text{ such that c.1) } 0 \leq a_{ki},\ \text{and c.2.a) } \sum_{k=1}^{d} a_{ki} = 1 \text{ or c.2.b)} \sum_{k=1}^{d} a_{ki} \leq 1, \quad (4)$$

where $\varepsilon_k, \eta \in R^n$ are random vectors such that $\varepsilon_k \sim N(\mu_k, \Gamma_k)$, $\eta \sim N(\mu_0, \Gamma_0)$, and $c = 0,1$. Constraint c.2.b may be used in place of c.2.a to account for variations in scale or as in remote sensing, scalar variations in illumination. Applied to remote sensing data, η models path radiance, additive sensor noise, and other additive terms. By choosing $c = 0$, and constraints c.1 and c.2.a, the model reduces to the Schaum–Stocker model. The present approach has the advantage that the parameter estimation procedure does not restrict the abundance values to a prescribed set, and the number of classes is not limited. This model reduces to the linear mixing model by choosing $\Gamma_k = 0$ for all $1 \leq k \leq d$ and $c = 1$, although the parameter estimation technique described below will not refine initial estimates of the μ_k in this case. It does, however, provide a maximum likelihood approach to estimating the parameters of the distribution of η. Furthermore, by imposing the constraints c.2.a and $a_{ki} = 0,1$ for each $1 \le i \le N$, exactly one of $a_{ki} = 1$, and the model encompasses the Gaussian mixture model.

2. Parameter Estimation

A sequence of parameter estimates is defined such that the limit of the sequence converges to a (local) maximum of the likelihood function based on the model (4). Initial values $\left(\mu_k{}^0, \Gamma_k{}^0\right)$ of the parameters were obtained by finding endmembers using linear unmixing techniques, identifying $\mu_k{}^0$ with the kth endmember, and estimating $\Gamma_k{}^0$ as the sample covariance of a cluster of observations near $\mu_k{}^0$. Abundance estimates are updated (UA) by maximizing the likelihood equation subject to constraints c.1 and c.2.a or c.2.b using current class parameters $\left(\mu_k{}^{j-1}, \Gamma_k{}^{j-1}\right)$ [2]. The class parameters are updated (UP) using the expectation-maximization equations derived in [2] and the current abundance estimates $\left\{a_{ki}{}^j\right\}$. Likelihood increases with each iteration of UA or UP. Thus, a sequence of parameter estimates of increasing likelihood is obtained by the application of a sequence of updates: UA, UP, UA, UP. The iteration is halted when a convergence criterion is satisfied.

3. Detection Algorithms

Both anomaly and likelihood ratio detection algorithms may be derived from the stochastic compositional model. If the target signature is unknown, then an anomaly detector is obtained by estimating the parameters of the data as described above and computing the log-likelihood of the observation, y^i, given the parameters:

$$A_S(y^i) = -L(y \mid H_0) = -\frac{1}{2}\log\left(\left|\Sigma(\alpha^i)\right|\right) - \frac{n}{2}\log(2\pi) - \frac{1}{2}\left(y^i - \mu\left(\alpha^i\right)\right)' \Sigma\left(\alpha^i\right)^{-1}\left(y^i - \mu\left(\alpha^i\right)\right), \tag{5}$$

where H_0 (H_1) indicates that the target parameters are not (are) included in the abundance estimate. An anomaly detection procedure is obtained by comparing (5) to a threshold. A likelihood ratio test may be derived from the SCM if a target signature is available. The log-likelihood ratio is then

$$L_S(y) = L(y \mid H_1) - L(y \mid H_0), \tag{6}$$

4. Detection Experiment

Detection algorithms derived from the linear unmixing model, a multi-variate Gaussian mixture model, and the stochastic compositional model were applied to the problem of detecting a personal flotation device (PFD) on the ocean surface. Ocean hyperspectral imagery (HSI), taken over case I water from the Central Pacific, and PFD radiance signatures coincident with the imagery data were available from an Office of Naval Research hyperspectral imaging program. The background scene consisted of a 125X125 image of 24 band data covering the portion of the spectrum from 415 to 830 nm. Test data for the detection experiment were obtained by combining the PFD radiance signature with the HSI at pixel fill fractions (PFF) of 5%. The receiver operating characteristic (ROC) curves of likelihood ratio and anomaly detection statistics applied to these data are shown in Figures 1a and 1b, respectively. Clearly, algorithms based on the stochastic compositional model have a greatly reduced number of false alarms.

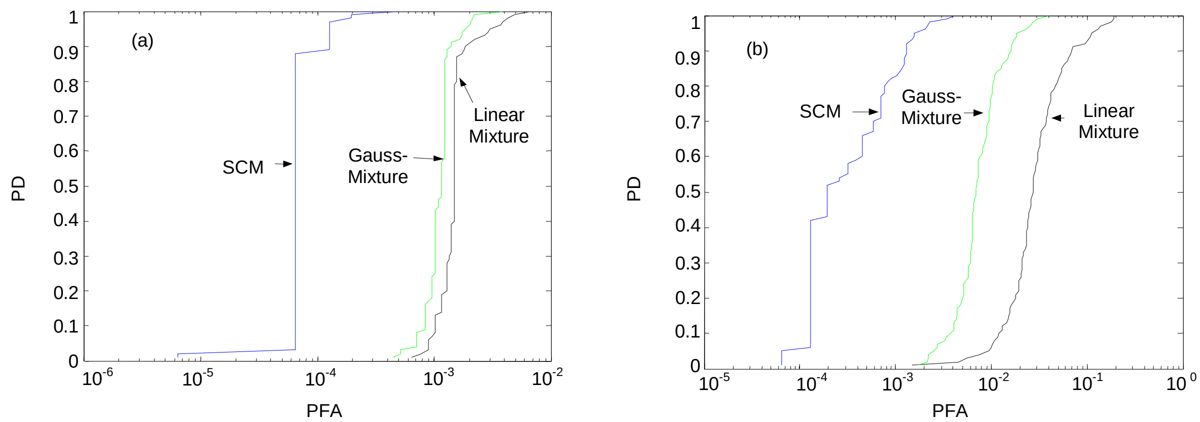

Figure 1. ROC curves of likelihood ratio (a) and anomaly detection (b) algorithms derived from the stochastic compositional model, the Gaussian mixture model, and the linear mixture model. Each target fills 5% of the pixel that contains it.

POTENTIAL NAVAL SIGNIFICANCE

The work outlined here is of theoretical significance for the improved modeling of hyperspectral imagery that incorporates mixed pixels, intra-class variability, path radiance, additive noise, scalar variation in illumination, maximum likelihood estimation of parameters, and anomaly and likelihood ratio detection algorithms based on detection theoretic principles. More generally, the methodology developed is applicable to mixture data from other sources. The methodology is of practical importance because of the improved performance in detection and classification that the approach offers.

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Environmental Adaptive Matched-Field Tracking

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The objective was to demonstrate automatic detection of a submarine in a littoral environment by using an inexpensive deployable line array of hydrophones. We did so by using a matched-field tracking (MFT) algorithm that resides in the deployed system. For real-time operation, the algorithm was implanted in a digital signal processor (DSP) chip. MFT works by finding a target track that has the highest value of correlation for a 3- to 5-minute period. The depth of the track is the discriminate used to separate submarines from surface ships. Work this year focused on the development of algorithms to be used with a six-hydrophone bottom line array in the Adriatic Sea, as part of the Remote Deployable Systems (RDS)-3 experiment. Good results were obtained from the deployment in littoral water near Bari, Italy.

SUMMARY

The hostile diesel-electric submarine is a serious and increasing threat to U.S. Navy/Marine operations in littoral waters. This threat will require development of detection systems with improved performance. At the same time, reduced Navy manning mandates systems with little or no operator input. The matched-field tracking (MFT) algorithm satisfies both requirements by matching the acoustic data with environmental calculations to generate estimates of target depth, speed, and direction. The designation of a target as submerged solves 98% of the classification problem.

Three techniques are used so that the MFT algorithm will operate in real time: (1) range-demodulation of the calculated sound field, (2) image warping of the normal mode depth functions, and (3) use of selected elements of the covariance matrix. These techniques will be explained in the following discussion about analysis of data from three sea tests.

Although the kernel of MFT is the common matched-filter, practical application of the algorithm requires searching for tracks in a five-dimensional space. These coordinates are the x and y values of A and B, and the target depth. This processing can be done in real time by storing the predicted range-demodulated hydrophone values in a large number of tables. Then, the track correlations are quickly calculated using table lookup. In the first data set, hydrophone data from six sensors of a vertical line array (VLA) located near San Clemente Island were used and results were published [1].

The second data set was related to tracking the research submarine USS *Dolphin* (AGSS 55) in Dabob Bay. Data were collected on a short bottom array. A selected set of frequency bins with the best (S+N)/N ratios, after constant-false-alarm-rate (CFAR) normalization, were used in the analysis. To obtain the required range-demodulated tables at the specific frequencies, image warping of the normal modes was used, while being careful to locate the zero-crossings and maximum response of the modes. The third data set was collected during the Remote Deployable Systems (RDS)-3 experiment in the Adriatic Sea in November 2000. To reduce the number of points in the initial search grid, only selected elements of the covariance matrix were used (i.e., those hydrophone pairs with separations <= 150 m). Mark Stevenson and Homer Bucker reported this work in a paper at the fall meeting of the Acoustical Society of America [2].

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Navigation and Applied Sciences

Nucleic-Acid Transfection Technology Development in Marine Mammals

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The principal goal of this project is to develop nucleic-acid transfection-based tools to protect Navy marine mammals from infectious diseases. The work involves a critical process of high-risk disease identification and construction of nucleic-acid-based tools, deoxyribonucleic acid (DNA) vaccines, and immuno-modulating sequences, to prevent specific marine-mammal diseases. Experiments using plasmids that express reporter-gene products have been central to producing proof-of-concept results. The final products will substantially reduce marine-mammal mortality and further enhance force protection.

SUMMARY

SSC San Diego trains and cares for marine mammals that are invaluable to the U.S. Navy and that are operationally integrated components of critical mine countermeasures, force protection, and deep-water object recovery detachments. A comprehensive preventive veterinary medicine program has been established to maintain marine-mammal health and to ensure mission readiness, in accordance with SECNAVINST 3900.41D. To this end, the veterinary staff continuously seeks means to improve preventive/diagnostic capabilities in order to clinically care for and protect Navy marine mammals so that they may protect service members and high-value Department of Defense (DoD) assets.

Vaccination of individuals within a population is perhaps the single most effective preventive medicine tool of the healthcare professional. Effective vaccination programs have radically reduced the prevalence of many human and animal diseases. Indeed, vaccination may eliminate some pathogens as threats (e.g., smallpox). Over 30 licensed and proven vaccines have been developed and are routinely used for humans, and over 25 vaccines are used for veterinary species. Eighteen human vaccines were developed and placed into use between 1960 and 1990, bringing the current total to 33 [1]. Even fish of commercial importance are protected against several diseases with specifically developed vaccines. However, there are no vaccines currently available for marine mammals.

Conventional vaccines are biological products containing either a live, modified live, or a killed preparation of the offending bacteria, virus, or parasite. In some cases, traditional vaccines can revert to a virulent form and cause disease, especially in immuno-compromised host animals or in animal species vaccinated “off-label.” Navy animals live and work in the open-ocean environment. They deploy regularly to waters distant from their home enclosures in San Diego. Consequenctly, the animals may be exposed to foreign organisms and potential health threats. Moreover, there is evidence that these animals have not been exposed to some of the known causes of disease and death in wild marine mammals such as morbilliviruses, and therefore, have no “natural immunity” [2].

Recent advances in the field of molecular biology have made it possible to induce the expression of specific genes in individual animals by transferring them via circularized pieces of deoxyribonucleic acid (DNA), called plasmids. Plasmid vaccines have been shown to induce long-lasting, humoral, cellular, and mucosal immunity. Mice have recently been protected from intracerebral injection of canine distemper virus (CDV) (a morbillivirus closely related to one infecting marine mammals) by intramuscular or intradermal inoculation with a plasmid encoding the CDV hemagglutinin protein [3]. To gain some determination of confidence in a transfected gene product, one must rely on measures of immune-system response to exogenously administered plasmids. Much of the effort in the early phases of any vaccine development for marine mammals must be focused on response assays. Once assays are developed and validated, one may confidently evaluate any number of potential vaccines or immunomodulating plasmids for use. This work is currently underway in our laboratory.

OBJECTIVE

The major objective of this research effort is to develop knowledge, methodologies, and reagents required to apply nucleic-acid transfection technology to Navy working marine mammals. The products will lead to the development and application of specific DNA vaccines and immuno-modulating plasmids for the protection of Navy marine mammals. Such results will substantially reduce morbidity and mortality for marine mammals and will enhance force protection.

APPROACH

The approach focused on four major areas: (1) database searches, (2) construction of DNA plasmids, (3) routes of transfection, and (4) assessment of immune response.

1. *Database Searches.* The first step was identification of the major causes of known and potential morbidity and mortality within the Navy animal population. This research was done by reviewing scientific literature and Navy Marine Mammal Program (NMMP) medical record archives and was facilitated by our recently completed comprehensive marine-mammal database. The infectious agents identified were continuously rank-ordered by incidence, and candidates for plasmid constructs have been identified.

2. *Construction of DNA Plasmids.* DNA plasmids of choice were constructed following routine cloning techniques in molecular biology. The expertise of Tracy Romano, Ph.D., from Texas A&M University; Peter Hobart, Ph.D., from Vical Inc.; and Branson Ritchie, Ph.D., the University of Georgia ensured training of the postdoctoral candidate, laboratory technicians, and graduate students in the field of molecular biology techniques needed to carry out this task.

3. *Routes of Transfection.* For most DNA vaccinations, the plasmid is introduced into either skeletal muscle or skin. An effective immune response requires antigen processing and presentation by so-called antigen presenting cells. These cells include tissue macrophages, dendritic cells, and Langerhan’s cells. Immune responses to plasmid vaccines have also been demonstrated with intravenous, intranasal, and oral administration. Our work to date has involved administration of DNA vaccines intramuscularly in two marine-mammal sites: (1) the cervical region of longissimus muscle and (2) the thoracolumbar region of the longissimus muscle. Ultrasound guidance was used to confirm injection of the vaccine into these muscle bodies.

4. *Assessment of Immune Response.* Administered vaccines were evaluated as to their efficacy based on the immune response. Assays were developed and adapted to look at humoral and cellular immune function in marine mammals. Moreover, molecular tools and reagents were developed in our laboratory to help assess immune function and to aid in assessing vaccine efficacy.

RESULTS

We are continuously assessing the infectious threats to our animals through analyses of in-house data and published literature. By understanding the infectious diseases that have caused morbidity and mortality within the Navy population, as well as the disease processes present in the areas to which our animals travel, we can focus on developing transfection technology that will positively contribute to maintaining the health of Navy working animals. Data mining and archiving has allowed us to identify significant health threats to this population of animals.

To date, we have identified dolphin morbillivirus as the most serious infectious threat to Navy dolphins. Dolphin morbillivirus has caused mass mortality in wild populations of cetaceans. The high death rate and persistence of the virus indicate that dolphin morbillivirus may have long-term effects on cetacean populations. Therefore, it is viewed by many scientists as one of the most serious infectious threats to cetaceans worldwide. All Navy marine mammals have been screened for exposure and immunity to morbillivirus infection. Results indicate that the population has not been exposed and is, therefore, likely susceptible to this infection.

As a direct result of this effort, a dolphin morbillivirus plasmid-based DNA vaccine has been constructed. Two of the dolphin morbillivirus proteins were selected and cloned for the vaccine based on known characteristics of the morbillivirus family. The hemagluttinin (H) protein was chosen because it is highly immunogenic and would likely induce a protective immune response in marine mammals. The fusion (F) protein of dolphin morbillivirus was selected because it is highly conserved between morbilliviruses and would, therefore, offer protection against new strains of marine-mammal morbilliviruses. Both genes have been cloned and inserted into Vical's plasmid vector, and the vaccine is currently being tested in a laboratory animal model at the University of Georgia.

To prepare for administering newly constructed plasmid vaccines to protect against target pathogens, we designed and completed a reporter-gene vaccine trial to demonstrate proof of concept. Two reporter-gene plasmids were chosen that encode for proteins eliciting an immune response but not disease. One plasmid encoded for B-galactosidase (B-gal), and the other encoded for human influenza A nucleoprotein (NP). Both plasmids were engineered and supplied by Vical, Inc. Baseline antibody titers to B-gal and NP were measured in a group of candidates, and two animals were selected for the study.

To measure the immune response to the reporter-gene plasmid vaccines, immunoassays were validated in our on-site laboratory under the direction of Dr. Tracy Romano. These immunoassays included enzyme-linked immunosorbent assays (ELISA) to measure antibody titers to both B-gal and NP, and lymphocyte proliferation assays to measure the cellular immune-system response to the plasmid antigens. Preliminary results strongly suggest that the animal receiving the B-galactosidase reporter-gene plasmid responded positively to the vaccine as determined by the lymphocyte proliferation assay (statistical analysis pending).

For the purpose of assay expansion, parallel experiments were conducted during the vaccine trial for the development of a new cytokine assay. Following isolation of lymphocytes from dolphin blood and stimulation of the lymphocytes with plasmid protein antigens, over 800 ribonucleic acid (RNA) samples were collected and archived for the quantification of cytokine mRNA. These data will allow us to map cytokine responses to vaccine antigens, and allow us to better target specific immune responses.

Safety of intramuscular plasmid DNA administration to dolphins has been demonstrated. In initial experiments, we vaccinated dolphins with plasmid vaccines encoding reporter genes. To date, we have administered 26 individual injections of plasmid doses ranging from 50 mcg to 1000 mcg in three dolphins. A total plasmid nucleic-acid dose of 3000 mcg has been administered to one test animal. Each animal was monitored closely during the vaccine trial, and there were bimonthly blood samples and health assessments. There has been no evidence of adverse reaction to the plasmid vaccines in any of the test animals.

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Detection of Ionic Nutrients in Aqueous Environments Using Surface-Enhanced Raman Spectroscopy (SERS)

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In-situ detection of anionic nutrients in the ppm-ppb concentration range using cationic-coated surface-enhanced Raman spectroscopy (SERS) substrates was demonstrated. Information on nutrient dynamics is used by the Navy to understand chemical reactions that impact marine environmental quality and to predict the distribution, growth, and community structure of biota in the coastal ocean. However, this same technology can be used to detect volatile organic compounds (VOCs). Because several naval facilities are impacted by VOC contamination, this effort was redirected to examine the use of thermoelectrically cooled SERS substrate to detect and identify VOCs. The original objective of this project was to develop thiol-coated SERS substrates to detect ionic nutrients (i.e., nitrate, sulfate, and phosphate) in aqueous environments. The effort was expanded in FY 01 to include detection of methyl-tertiary-butyl ether (MTBE) and other VOCs in aqueous environments.

SUMMARY

Methyl-tertiary-butyl ether (MTBE) is a contaminant of increasing environmental concern. MTBE is an additive in gasoline used as an oxidant to facilitate combustion and thereby reduce air emissions. This additive is very soluble in water and is resistant to biodegradation. Because of its solubility, MTBE is a mobile contaminant and is a bigger threat to groundwater than petroleum hydrocarbons. MTBE has been detected in wells. Water contaminated with MTBE, at ppb concentration levels, has a disagreeable taste and odor. Its impact on human health is not fully understood. Some studies indicate that MTBE is a carcinogen. The Navy has environmental quality research and development (R&D) requirements through the Naval Facilities Command (NAVFAC). There are at least three baseline assessment memorandums (BAMs) in which this technology is applicable: “Sensor/Control System for Managing Effluent Discharges,” “Assessment of Non-Point Source Runoff Impacts on Receiving Water Systems,” and “Advanced Site Characterization and Analysis Penetrometer System (SCAPS) Sensors for Source Characterization and Remediation Monitoring.” The MTBE problem has direct impact on Navy facilities and on the ability of the Navy to close facilities under Base Realignment and Closure (BRAC). In a letter to Andy Del Collo, program manager of NAVFAC’s Pollution Abatement Ashore (Y0817) project, Brian S. Gordon, Director, Water Program of Navy Region Southwest (NRSW) stated:

> *The Navy Region Southwest (NRSW), Environmental Department, currently is responsible for the characterization, cleanup, and closure of numerous sites that have been impacted with Methyl Tertiary Butyl Ether (MTBE) as well as other Volatile Organic Compounds (VOC). Navy wide, the scope of VOC and MTBE characterization efforts is truly immense. Due to the complex nature of groundwater migration in the subsurface, characterization and cleanup of these sites is very expensive and time consuming. I have found that real-time, in-place characterization techniques with real-time soils data have proven to be of great cost savings to the Navy. I believe the Navy could save millions of*

dollars per year by completely understanding subsurface conditions before beginning expensive cleanup operations.

Current methods to delineate MTBE plumes require extensive sampling and outside laboratory analysis. These methods are costly and time-consuming, There are currently no *in situ* approaches available to do these characterizations. Unless a better way is found, three-dimensional characterization of these sites will place a huge financial burden on the Navy. Due to this clear Navy need for an *in-situ* sensor to detect MTBE and other VOCs, this ILIR project was redirected to evaluate detection of these compounds by SERS.

The SERS technology is not limited to the detection of ionic nutrients. This technology has been used to detect metal ions and VOCs including benzene, toluene, ethylbenzene, and xylene (BTEX) and chlorinated solvents in water. MTBE is a VOC that does not fluoresce, but it does have a characteristic Raman signature that will allow it to be detected and identified by SERS. The proposed action level for MTBE is 40 ppb. Despite the sensitivity of SERS, this will require a pre-concentration step. In an earlier Strategic Environmental Research and Development Program (SERDP) effort, Angel et al. [1] developed a thermoelectric (TE)-cooled probe for normal Raman spectroscopy that they were able to use to detect 1000 ppm CCl_4.

To detect MTBE and other VOCs, a TE-cooled probe is coupled with a coated SERS substrate. Although MTBE is very soluble in water, it is an organic material and is volatile (bp = 55.2 ^{o}C). Consequently, it can be displaced from the water by sparging with an inert gas such as nitrogen. The vapors can then be concentrated onto a thiol-coated SERS substrate by using a thermoelectric cooler (TEC). In this instance, the purpose of the thiol coating is to stabilize the SERS surface, thereby extending its lifetime, and to provide an internal calibration standard. Figure 1 shows a schematic of the TEC-SERS laboratory system.

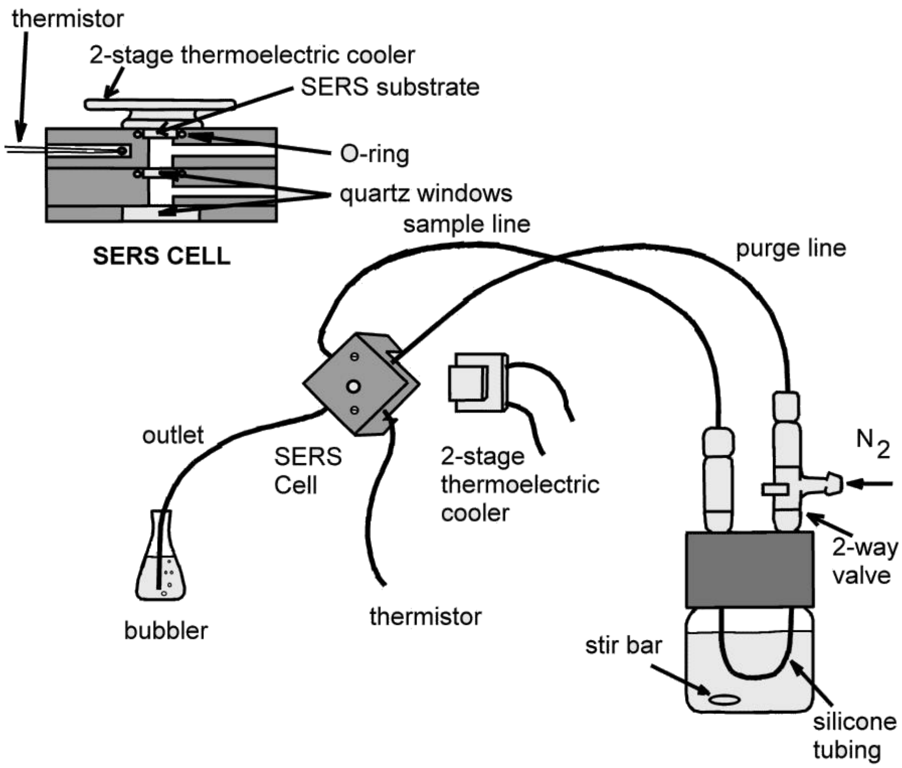

Figure 1. Schematic of the TEC-SERS laboratory system.

The results summarized in Figure 2 indicate that MTBE can be displaced from the water and detected by its SERS response. A 500-ppm MTBE solution was placed in the sample beaker shown in Figure 1. To drive MTBE out of the water required heating the sample to 70 to 80 ^{o}C. The silicone tubing in the sample beaker only allows organic vapors through to the TEC-SERS sensor. The silver SERS substrate was coated with 1-propanethiol. The SERS spectrum of the coating is shown in Figure 2a. Figure 2b shows spectra of the Ag/1-propanethiol substrate in the presence of MTBE at 0 °C and –5 °C. The spectral contributions of 1-propanethiol have been subtracted out. The MTBE peaks are designated with an M. The bottom spectrum in Figure 2b is that of neat MTBE. At 0 °C, the MTBE vapors do not condense onto the SERS substrate. However, at –5 °C, MTBE does condense onto the SERS substrate. The peaks due to MTBE on the substrate directly correspond with those for neat MTBE, which facilitates speciation. Efforts are ongoing to design and build a cone-penetrometer-deployed TEC-SERS probe to be used to delineate subsurface VOC contamination.

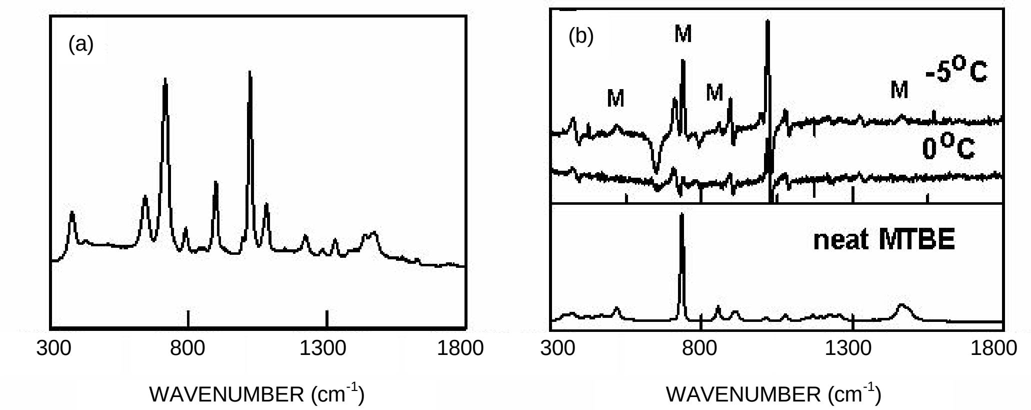

Figure 2. (a) SERS spectrum of a silver substrate coated with 1-propanethiol. (b) Top spectra are of the Ag/1-propanethiol substrate in the presence of MTBE at 0°C and –5°C. Spectral contributions of 1-propanethiol have been subtracted out. The MTBE peaks are designated with an M. Bottom spectrum is of neat MTBE.

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Toward an Assessment of Flow-Induced Bioluminescent Signatures

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The project goal is to provide a science-based predictive capability for assessing vulnerabilities and opportunities associated with flow-induced bioluminescence. This goal was pursued in two ways: One way was to characterize a "standard" bioluminescence-potential flow agitator recommended by the Naval Oceanographic Office. The other way was to collect and interpret images of flow-induced bioluminescence associated with a submerged jet. By using different concentrations of cultures of the red-tide dinoflagellate Lingulodinium polyedrum, it was shown, as anticipated, that the bioluminescence potential scales with concentration. However, for flow rates less than approximately 0.2 L s^{-1}, it was also found that bioluminescent-potential measurements were strongly dependent on flow rate. Similar behavior was found when the experiments were repeated with mixed plankton samples. This finding has important ramifications if the Navy intends to use similar flow agitators at lower speeds (e.g., in unmanned undersea vehicles [UUVs]/buoys). For the jet flow experiments, dinoflagellate cultures of Lingulodinium polyedrum, Pyrocystis fusiformis, and Ceratocorys horrida were each found to exhibit a unique bioluminescent "footprint" in response to the jet. We are presently characterizing both the flow agitator and jet flow fields by using digital particle imaging velocimetry.

SUMMARY

Over the past 40 years of scientific observation, bioluminescence has been found to be one of the most cosmopolitan organism behaviors in the marine environment. The occurrence of bioluminescence has been found in all oceans of the world and at all depths, and has been considered so widespread that its absence is considered more remarkable than its presence. To our knowledge, the first published studies quantifying the threshold for flow-induced bioluminescence were performed by the authors of this proposal through support from ILIR (1993–1995) and ONR (1994–1996). These studies included both cultured dinoflagellates and freshly collected plankton samples and have repeatedly and consistently found (in laminar flow) a response threshold at shear stress values of 1 to 3 dynes cm^{-2}. This level of agitation is significantly less than what was previously thought necessary for stimulation, and consequently, the volumes of supra-stimulatory flow are much greater than previously anticipated.

With knowledge of shear-stress-threshold values for bioluminescence stimulation, it is inviting to estimate the potential spatial "footprint" of bioluminescence in many well-studied flows. However, how laminar-flow threshold levels extrapolate to turbulent flows is not known. There are many precedents for applying measurements obtained in laboratory laminar flows directly to turbulent, oceanic processes. The common argument is that organisms less than the smallest energetic eddy scale will experience turbulent flow as a laminar, approximately linear, velocity gradient whose magnitude is determined by the dissipation. Yet, even if the flow is laminar at the scale of the organisms, it is unsteady. Consequently, it is necessary to test whether the bioluminescence threshold values determined in laminar, internal flows could be applied to turbulent, external flows. Since a submerged turbulent jet is well characterized, it was chosen to study as a possible candidate, i.e., did it produce a robust bioluminescence signature?

We had also been asked by Mark Geiger of the Naval Oceanic Office to try to characterize one of the instruments they use to provide an index of bioluminescence potential. This attempt is important because one did not know how to compare measurements from similar instruments where the flow rates were different.

OBJECTIVE

Our ultimate goal is to provide a science-based, predictive capability for assessing vulnerabilities and opportunities associated with flow-induced bioluminescence. This study includes the ability to predict the bioluminescence "noise" of naturally occurring events in the ocean. For the near term, we start with simple laboratory flows, determine repeatable patterns, and progress toward more complex flows. We have performed over 50 internal, predominantly laminar-flow, laboratory experiments (pipe flow, Couette flow, converging nozzle flow) and are now progressing to an external, turbulent flow (jet). Furthermore, by characterizing oceanic devices for measuring bioluminescence potential within the laboratory, it is hoped that the Navy can better use the large database already collected with these devices.

APPROACH

Laminar pipe flow data were first collected for the three dinoflagellates species: *Lingulodinium polyedrum*, *Pyrocystis fusiformis*, and *Ceratocorys horrida*. An 80-liter jet-flow apparatus was then built where the responses of these same organisms were tested for Reynolds (Re) numbers between 550 and 10,000. Here the Re number is based on a jet diameter of 0.2 mm. Images of the bioluminescent jets could then be compared with various flow attributes (dissipation, Reynolds shear stress, turbulent intensity) of the jet. These attributes will be drawn from the literature for classical jets and from digital particle-imaging velocimetry measurements of the jet.

Characterization of the bioluminescence flow agitator entailed measuring the response of freshly collected mixed plankton samples as well as cultures of *Lingulodinium polyedrum* at different concentrations and flow rates. The streak patterns provided by *Pyrocystis fusiformis* were used to visualize flow patterns within the agitator. These patterns would be checked and quantified by digital particle-imaging velocimetry.

RESULTS

The relative sensitivity of the three dinoflagellates tested in the jet was the same as found in pipe flow, i.e., *Ceratocorys horrida* was more sensitive than *Pyrocystis fusiformis*, which was more sensitive than *Lingulodinium polyedrum*. Each species produced a robust and unique bioluminescent signature. *C horrida* sparkled; *Pyrocystis fusiformis* formed streaks; and *Lingulodinium polyedrum* produced a cloud-like image. Digital particle-imaging velocimetry measurements have been made at the same flow speeds and, after analysis, will be compared with the bioluminescence images to best determine which flow parameters best mark where bioluminescence is stimulated.

The bioluminescence-potential flow-agitator measurements with cultures of *Lingulodinium polyedrum* scaled with concentration (0.1, 1, 10, and 100 cells ml^{-1}). Between volumetric flow speeds of

0.2 and 2 L s^{-1} (highest studied) bioluminescence-potential measurements were independent of flow. However, for volumetric flow speeds less than 0.2 L s^{-1}, bioluminescence-potential levels dropped off dramatically.

POTENTIAL NAVAL SIGNIFICANCE

Fish do it. Seals do it. Dolphins do it. Swimmers do it. Surface ships do it. In fact, the last German U-boat detected in the Great War was sunk because it did it. What they all do is create flow fields energetic enough to leave bioluminescent “footprints.” We believe that night surveillance of the bioluminescent wakes of submarines, swimmers, UUVs, and mines would be a valuable complement to existing fleet capabilities. In coastal areas, due to the large concentrations of dinoflagellates, the potential for night observance of flow-induced bioluminescence is greatest. It is in these very coastal waters, where conventional antisubmarine warfare (ASW) acoustic surveillance is severely challenged, that an additional capability would be most welcome. Moreover, the distinct spectral signature of bioluminescence dinoflagellates makes them ideal candidates for exploitation by emerging multispectral technology.

In order to begin to make predictions of potential bioluminescence “signatures” of ships, swimmers, and underwater vehicles, one must know something about the following: threshold levels of hydrodynamic agitation necessary for bioluminescence stimulation, the corresponding hydrodynamic flow field, and how to estimate bioluminescence intensity based on standard Navy bioluminescence potential measurements. Some progress has been made in each of these areas. We have, for laboratory laminar flows, repeatedly established a shear-stress threshold of the order 1 dyn cm^{-2} (or equivalently, an energy dissipation, per unit mass, threshold of 10^2 cm^2 s^{-3}) for many luminescent dinoflagellates. Working with Dr. Mark Hyman of the Naval Surface Warfare Center (NSWC), we have run numerical simulations of ship wakes and calculated potential bioluminescence “footprints” based on laboratory-determined threshold levels. Estimates of the length of the bioluminescence wake of an aircraft carrier differ greatly depending on whether turbulent shear stress or dissipation is used as the criterion for threshold. Quantitative wake measurements of bioluminescence are necessary to determine suitable transfer functions between the numerical models, bioluminescence-potential measurements, and actual observations. Meanwhile, through studying the bioluminescence associated with a submerged jet, we hope, within a laboratory context, to begin to understand how to extrapolate results derived from laminar, internal flows to turbulent, external flows. Finally, by beginning to characterize how bioluminescence-potential measurements are sensitive to flow speed and concentration of luminescent dinoflagellates, we can better guide the Navy in future designs of bioluminescent flow agitators and in interpreting measurements from similar flow agitators.

Micro-Electro-Mechanical Systems (MEMS) Ultra-Sensitive Accelerometer (USA)

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This project addresses the military's need for a low-cost, highly sensitive micro-electro-mechanical systems (MEMS) ultra-sensitive accelerometer (USA). To meet this need, the design and fabrication of a small, lightweight, highly sensitive optical accelerometer that could sense changes in gravity better than one part per million was proposed. The result of this FY 01 effort was the first successful fabrication and electrical testing of a Fabry–Perot interferometer monolithically integrated with a photodiode on a complementary metal-oxide semiconductor (CMOS)-compatible silicon substrate. All MEMS USAs were designed, fabricated, and electrically tested at SSC San Diego's Integrated Circuit Fabrication Facility (ICFF). We demonstrated that this novel sensor possessed transistor-like characteristics with a measured transconductance of 1 mA/V, an output resistance of 110 MΩ, and a maximum small-signal voltage gain of 430 V/V. The fabrication and electrical test results verify the proof-of-concept (POC) for this novel accelerometer.

SUMMARY

The development and insertion of the Global Positioning System (GPS) into military applications has resulted in increased situational awareness by supplying highly accurate and timely positional information. The GPS signal received from satellites, however, is weak and susceptible to interference from external sources. Accurate knowledge of position is critical for the warfighter, and, therefore, alternative methods to determine position as either an enhancement or as a backup to GPS are required. An alternative method is also needed for cases where a GPS signal is simply not available, e.g., submarine navigation. One possible method that has been extensively investigated is the use of micro-electro-mechanical systems (MEMS)-based inertial measurements units (IMU). These MEMS IMUs can be divided into the measurement of angular displacement (gyroscopes) or the measurement of linear displacement (accelerometers). Both types of IMUs are required for highly accurate positional and navigational information. Traditional pickoff techniques for determining both angular and linear displacements have relied on either the capacitive or piezoresistive/piezoelectric methods. While both methods work well for relatively large macroscopic systems where signal-to-noise ratios (SNRs) are large, they are inherently limited by fundamental noise sources as their dimensions are reduced to hundreds of microns or less.

The displacement measurement techniques listed above are physically limited in sensitivity by their size and depend on state-of-the-art electronics to achieve their levels of accuracy. Furthermore, sensors based on these physical mechanisms depend on extremely tight processing control, which results in poor yields and increased fabrication expense. The trend has been to increase the size and mass of these sensors for high-sensitivity applications, thus further increasing fabrication expense and decreasing the number of potential sensors per wafer. Summarizing the above descriptions, Anthony Lawrence [1] states "…There is no accelerometer yet that is capable of replacing the PIGA (Pendulous Integrated Gyroscopic Accelerometer)—the world definitely needs a smaller, less expensive, more reliable, accelerometer of PIGA performance."

OBJECTIVE

The objective of this FY 01 project was to design, fabricate, and electrically test a small, sensitive, lightweight optical MEMS accelerometer sensor. A secondary objective was to further the science of optical MEMS-based devices and mechanical transistors.

APPROACH

Conventional techniques such as those discussed above may use the proof mass as one of two plates of a parallel plate capacitor in order to detect displacement of a proof/inertial mass attached to a spring. The novel optical approach presented here, however, utilizes the small wavelength and the resonant-wave nature of light to detect the displacement of a proof mass attached to a spring.

To use the resonant-wave nature of light and its exponential sensitivity, we fabricated a Fabry–Perot interferometer monolithically integrated with a photodiode on a complementary metal-oxide semiconductor (CMOS) compatible silicon substrate. Such a combination results in a means to increase the SNR while also increasing the sensitivity via the resonant optical cavity as compared to conventional MEMS-based accelerometers.

A Fabry–Perot interferometer first devised by C. Fabry and H. Perot in 1899 employs multiple beam interference. This interferometer is typically used to measure wavelengths with high precision and to study the fine structure of spectral lines. A Fabry–Perot etalon or cavity consists of two optically flat, partially reflecting mirrors held parallel with respect to one another. The transmission of monochromatic light through such a structure is extremely sensitive to the spacing between the mirrors and can, therefore, be used to detect minute displacements of one mirror in reference to the second fixed mirror. The displacement, in this case, is due to perturbations caused by small accelerating forces.

Additionally, the integrated photodiode provides a means to not only detect the change in transmitted light intensity, due to a change in position of the mirror, but also provides a convenient high-gain amplifier, as will be discussed.

OPERATION

The analysis of the proposed structure has two components: (1) the transmission of light through the Fabry–Perot cavity for a variable mirror spacing and (2) the change in mirror spacing as a function of the applied force.

The transmission/reflection of light through the Fabry–Perot cavity for a fixed mirror spacing, d, with monochromatic light incident normal to the surface of the top mirror, is dependent on the wavelength of light and the effective cavity length. The transmitted light into the photodiode reaches a maximum if there exists an integral multiple of half wavelengths within the effective cavity. If the effective cavity length changes from this resonant condition due to a perturbing accelerating force, the transmitted light is attenuated and the collected photocurrent within the photodiode is reduced. From this change in photocurrent, the change in position and, hence, acceleration can be deduced. The amount of displacement for a given accelerating force depends on the mass of the mirror as well as the effective spring constant as given by Hooke's Law.

This device also possesses small-signal voltage gain since it is a three-terminal device and inherently possesses a "transistor-like" element. The three terminals are composed of a top mirror, bottom mirror or p^+ region, and n-type substrate. Since the position of the top mirror is controlled by force, the device provides a means to amplify either small input voltage signals applied to the top mirror or small displacements in the position of the top mirror due to accelerating forces.

RESULTS

Since the project dealt with the development and demonstration of a POC MEMS USA sensor, the sensor design and fabrication constituted a significant portion of the FY 01 effort. The MEMS USA device is truly a novel concept, and no other work existed for a comparison of baseline design. Great care was therefore taken to ensure that the initial design was robust and would have a high probability of success, not only in fabrication but also POC testing. Incorporated in the design were 145 different accelerometer geometries, each with a different spring constant, acceleration sensitivity range, and resolution level. All 145 designs occupied a die space of 9x9 mm that was repeated 121 times across the 150-mm silicon wafer. In addition, each 9x9 mm die was partitioned into 3x3-mm chips that could be bonded to metal TO packages. The micrographs of Figures 1 and 2 show an example MEMS USA sensor. Figure 1 shows the entire sensor including the three contacts. Figure 2 shows the upper mirror suspended above the lower mirror.

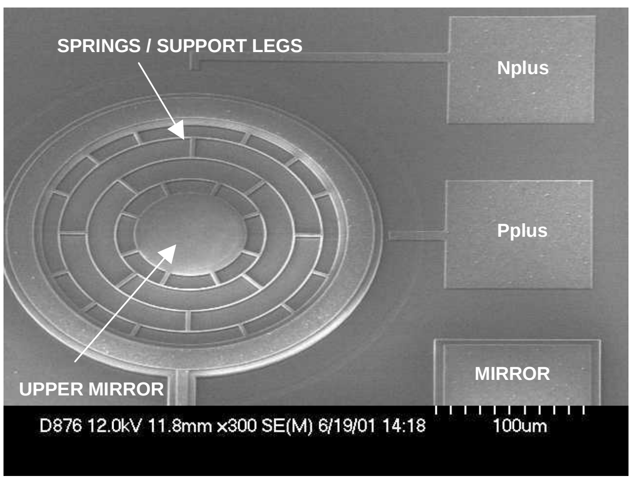

Figure 1. Entire MEMS USA sensor including the three contacts.

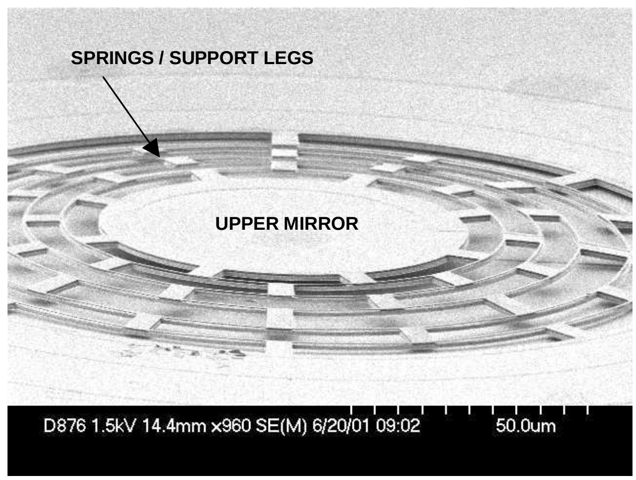

Figure 2. Released upper mirror suspended above the lower mirror by the springs.

All electrical characteristics of the MEMS USA sensor were measured with an HP4156 semiconductor parameter analyzer with current resolution capabilities of 10×10^{-15} A. The modulation characteristics of the MEMS USA device were measured by applying a linearly varying electrostatic potential, i.e., force, across the upper and lower mirrors of the sensor while simultaneously applying a constant reverse-bias voltage across the photodiode. The application of this variable force across the mirrors results in a change in airgap distance between the two mirrors and, hence, a change in the transmission coefficient through the mirrors and into the underlying photodiode where it is collected as a photo-generated current. By measuring the photocurrent with the change in applied force across the mirrors, a maximum transconductance of 1 mA/V was obtained. This large value for the transconductance of the first-generation MEMS USA sensor is within a factor of 10 of that obtained by comparable state-of-the-art silicon homojunction bipolar-junction transistors (BJT). In addition, the value of the transconductance was shown to be a function of the input laser power density that was applied orthogonally to the surface of the two mirrors. This observation was in agreement with the theory that was developed based on a first-principles analysis.

It was also demonstrated that the MEMS USA sensor possesses transistor-like characteristics capable of amplification. A family of curves, similar to that of a metal-oxide-semiconductor field effect transistor (MOSFET) or BJT, was obtained by fixing the electrostatic potential across the mirrors and sweeping the voltage across the reverse-biased photodiode. After the reverse-bias voltage was swept, the potential and, hence, distance between the mirrors were changed, and again, the voltage across the diode was swept resulting in a second distinct curve. In this manner, a family of curves was generated. The output resistance of the MEMS USA sensor extracted was 100 Mohm. This extremely high output resistance results in an almost ideal current source and is almost 100 times greater than the output resistance of a typical silicon MOSFET.

Once the transistor-like characteristics of the device were verified, the small-signal voltage gain of the device was measured. This voltage gain was extracted by applying an ideal load, i.e., current source, to the MEMS USA sensor and measuring the change in output voltage with change in input voltage (force). The maximum small-signal voltage gain achieved was 430 V/V for the sensors measured.

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Han, J., J. R. Zeidler, and W. Ku. 2001. "Chirp Transfer Functions in LMS Adaptive Predictors," 35th Asilomar Conference on Circuits, Systems and Computers, 4 to 7 November, Pacific Grove, CA, http://icas.ucsd.edu/icas/faculty/zeidler/students/jHan/asi_110501.pdf

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Rubin, S. H. 2000. "The Integration of Data Mining and Expert Systems," (plenary) keynote address, 2nd Annual Information Integration and Reuse Conference (IRI 2000), sponsored by the International Society for Computers and Their Applications (ISCA), 1 to 3 November, Honolulu, HI.

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Rubin, S. H. 2001. "Next-Generation Intelligent Systems," keynote address, 18th Annual Federal Database Colloquium and Exposition, 30 August, San Diego, CA.

Rubin, S. H. 2001. "The Importance of Knowledge Amplification in Learning," Ocean Engineering Society, Orincon Corporation, 3 October, San Diego, CA.

Rubin, S. H., J. Boerke, and R. Rush Jr. 2001. "The Intelligent Web is Coming," Position Paper, IEEE International Conference on Systems, Man, and Cybernetics, 7 to 10 October, Tucson, AZ.

Rubin, S. H. and M. G. Ceruti. 2001. "Application of Extended Plausible-Reasoning Theory to Fuel-Cell Design," IEEE International Conference on Systems, Man, and Cybernetics, 7 to 10 October, Tuscon, AZ.

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Rubin, S. H., J. Murthy, M. Milanova, R. J. Rush Jr., and J. Boerke. 2001. "A Third-Generation Expert System," 3rd Annual Information Integration and Reuse Conference, (IRI 2001), sponsored by the International Society for Computers and Their Applications (ISCA), 27 to 29 November, Las Vegas, NV.

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Rubin, S. H. and L. Trajkovic. 2001. “On the Role of Randomization in Software Engineering,” invited presentation, 28th International Conference on Computers and Industrial Engineering (ICC&IE), 6 March, Cocoa Beach, FL.

Rubin, S. H. and L. Trajkovic. 2001. “On the Role of Randomization in Minimizing Neural Entropy,” invited presentation at the 5th World Multiconference on Systemics, Cybernetics, and Informatics (SCI 2001), 22 to 25 July, Orlando, FL.

Schock, T. B., W. Van Bonn, T. A. Romano, S. E. Poet, and B. W. Ritchie. 2001. “Assessment of the Humoral Immune Response to Nucleic Acid Vaccination in the Bottlenose Dolphin (*Tursiops truncates*),” 32nd Annual IAAAM (International Association for Aquatic Animal Medicine) Conference and Workshop, 28 April to 2 May, Tampa, FL.

Smith, C. R., W. Van Bonn, T. A. Romano, P. Melnyk, E. Jensen, and S. H. Ridgway. 2001. “Application of DNA Vaccine Technology to Marine Mammal Medicine,” 32nd Annual International Association for Aquatic Animal Medicine (IAAAM) Conference and Workshop, 28 April to 2 May, Tampa, FL.

Stein, D. W. J. 2001. “Anomaly and Target Detection Applications,” invited presentation to the Office of the Secretary of Defense Battle Space Environments, Technology Area Review and Assessment, 6 to 8 March, Hanscom Air Force Base, Lexington, MA.

Stein, D. W. J. 2001. “Modeling Variability in Hyperspectral Imagery Using a Stochastic Compositional Approach,” IEEE International Geoscience and Remote Sensing Symposium, 9 to 13 July, Sydney, Australia.

Stein, D. W. J. 2001. “Stochastic Compositional Models Applied to Subpixel Analysis of Hyperspectral Imagery,” SPIE, Imaging Spectrometry VII, 1 to 3 August, San Diego, CA.

Stein, D. W. J. 2001. “Stochastic Compositional Models,” Joint Statistics Meeting, 5 to 9 August, Atlanta, GA.

Stein, D. W. J. 2001. “Subpixel Analysis of Hyperspectral Imagery Using a Stochastic Compositional Approach,” Air Force Research Laboratory (AFRL) Colloquium, 24 August, Hanscom Air Force Base, Lexington, MA.

Stein, D. W. J., S. G. Beaven. 2001. “Preprocessing Transforms and Target Detection from Hyperspectral Imagery,” Military Sensing Symposium, Specialty Group on Camouflage, Concealment, and Deception, 5 to 7 March, Vienna, VA.

Stocker, A., E. Ensafi, S. Beaven, and D. Stein. 2001.“Joint Algorithm Exploitation (JALEX): Fusion of Spectral Anomaly Detection Statistics,” Military Sensing Symposium, Specialty Group on Camouflage, Concealment, and Deception, 5 to 7 March, Vienna, VA.

Torrez, W. C., D. Bamber, and I. R. Goodman. 2001. “Information Assurance Considerations for a Fully Netted Force: Implementing CRANOF for Strategic Intrusion Assessment and Cyber Command and Control,” Fourth International Conference on Information Fusion, (Fusion 2001), special session on Situation Analysis and Situation Awareness, 7 to 10 August, Montréal, Québec.

Torrez, W. C**.,** I. R. Goodman, D. Bamber, and H. T. Nguyen. 2001. "Applications of a Second-Order Probability Inference System to Strategic Assessment and Cyber Command and Control," Military Sensing Symposia (MSS) National Symposium on Sensor and Data Fusion, 26 to 28 June, San Diego, CA.

HONORS AND AWARDS

HONORS AND AWARDS

Dr. Donald Bamber won an SSC San Diego Publication Merit Award for a Command and Control Research and Technology Symposium conference proceedings article on "How Probability Theory Can Help Us Design Rule-Based Systems."

Paul Baxley continues as President and Regional Chapter Representative of the San Diego Chapter of the Acoustical Society of America (ASA). He is Chairman of the ASA Public Relations Committee, a Member of the ASA External Affairs Committee, and Co-Chair of the ASA Home Page Committee. He is also a member of the ASA Underwater Acoustics Technical Committee and is a member of the Institute of Electrical and Electronic Engineers (IEEE) Marine Technology Society.

Dr. Homer Bucker is a recipient of the Acoustical Society of America Silver Medal (Pioneers of Underwater Acoustics) and received the National Defense Industrial Association (NDIA) Bronze Medal as a 2001 Special Achievement Award. This award recognizes individuals who have made significant contributions in the field of undersea warfare.

Dr. I. R. Goodman is serving as ongoing (1995 to present) associate editor of *Information Sciences*. He was also invited by D. S. Malik and J. N. Mordeson to write the preface for the forthcoming book, *Fuzzy Discrete Structures*.

Dr. Frank Hanson won an SSC San Diego Publication of the Year Award for Articles in Conference Proceedings for the paper he coauthored on "Relative Ladar Performance in Littoral Environments—The Case for Mid-IR Coherent Laser Radars," *Meeting of the Infrared Information Symposia (IRIS) Specialty Group on Active Systems*, vol. 1, pp. 59–76.

Dr. Stephen Hobbs won an SSC San Diego Publication of the Year Award for Technical Reports as one of six authors of TR 1796, an SSC San Diego technical report on " Signal Processing and Data Fusion for Deployable Autonomous Distributed Systems."

Dr. Visarath In is serving as an organizer for the ONR-sponsored 7th Experimental Chaos Conference to be held in San Diego 25 to 29 August 2002.

Douglas Lange served as Agencies Chair and committee member for the Rapid System Prototyping (RSP) 2001 conference as well as Session Chair for RSP 2000.

Dr. Pamela Mosier-Boss is a member of the OnSite-2002 scientific board and an organizer of the Tenth International Conference, On-Site Analysis, held 22 to 25 January 2002 in San Diego. On-Site is an international meeting of manufacturers, researchers, and end-users of field analytical chemistry equipment and services.

Dr. James Rohr won an SSC San Diego Publication Excellence Award for Open Literature for a *Limnology and Oceanography* article he coauthored entitled "Luminescent Response of the Red Tide Dinoflagellate Lingulodinium Polyedrum to Laminar and Turbulent Flow," vol. 44, pp. 1423–1435.

Dr. Stuart Rubin has been elected to the Administrative Committee of IEEE's Systems, Man, and Cybernetics Society for the term October 2001–December 2003. He served as Chair for the 2001 IEEE International Conference on Systems, Man, and Cybernetics panel on Intelligent Systems for

Gaining and Delivering Knowledge over the Internet. Dr. Rubin also served as Session Chair at the 28th International Conference on Computers and Industrial Engineering (ICC & IE) / Industry, Engineering, and Management Systems (IEMS) joint conference in March 2001, and at the International Conference on Mathematics and Engineering Techniques in Medicine and Biological Sciences (METMBS) in June 2001, and at the 5th World Multiconference on Systems, Cybernetics, and Informatics in July 2001.

Dr. Sri Sritharan won an SSC San Diego Distinguished Award for Open Literature for his article on "Deterministic and Stochastic Control of Navier-Stokes Equation with Linear, Monotone, and Hyperviscosities," *Applied Mathematics and Optimization*, vol. 41, pp. 255–308.

Dr. David Stein and **Dr. Stephen Stewart** won an SSC San Diego Publication Excellence Award for Conference Proceedings for the SPIE proceedings paper they coauthored with G. Gilbert and J. Schoonmaker on "Band Selection for Viewing Underwater Objects Using Hyperspectral Sensors," *Airborne and In-Water Underwater Imaging*, vol. 3761, pp. 50–61.

Dr. William Van Bonn was elected to the Executive Board of the International Association for Aquatic Animal Medicine (IAAAM). He was appointed as a National Research Council (NRC) Research Advisor for SSC San Diego and was accepted as an NRC Research Associate.

Dr. James Zeidler is a Fellow of IEEE and a technical reviewer for *IEEE Transactions on Communications*, *IEEE Transactions on Vehicular Technology*, *IEEE Journal on Selected Areas of Communications*, and *IEEE Transactions on Signal Processing*. Dr. Zeidler has been an Adjunct Professor of Electrical and Computer Engineering at the University of California, San Diego (UCSD) since 1989. He is affiliated with the Wireless Communications Center, the National Science Foundation Industry/University Cooperative Research Center on Ultra-High Speed Integrated Circuits and Systems, and the California Institute on Telecommunications and Information Technology. Dr. Zeidler has been recognized at SSC San Diego for his numerous publications. He won an SSC San Diego Publication of the Year Award for Open Literature for an *IEEE Transactions of Signal Processing* article he coauthored on "Nonlinear Effects in LMS Adaptive Equalizers," vol. 47, no. 6, pp. 1570ff. He also won an SSC San Diego Publication Distinguished Award for Conference Proceedings for a paper he coauthored on "Sensitivity Analysis of the Performance of a Diversity Receiver," *Proceedings of the IEEE International Conference on Communications*, vol. 3, pp. 1598–1602 and an SSC San Diego Publication Merit Award for Open Literature for an *IEEE Transactions of Signal Processing* article he coauthored on "The Effects of PN Sequences on the Misconvergence of the Constant Modulus Algorithm (CMA)," vol. 46, no. 2, pp. 519ff.

PATENT ACTIVITY

PATENTS ISSUED

Carol A. Becker **"Light-Activated Polymeric Actuators"**

Visible light causes a pH charge *in situ* to the polymer backbone. The pH charge expands and contracts the polymeric actuator in a timeframe suitable for robotics. A mechanism is provided for reversible dissipation of any heat produced by the light.

Patent 6,143,138; Navy case 78,990 (Serial 09/137,008) filed 20 August 1998; issued 7 November 2000.

Stephen M. Hart **"Optoelectronically Controlled Frequency-Selective Surface"**

A photovoltaic field-effect transistor (PVFET) is used to control the impedance, scattering frequency, and scattering cross-section of the scattering elements on a frequency-selective surface. The PVFETs are implanted in the arms of either wire or slot scatterers to make their scattering properties adjustable. The resulting optoelectronically controlled frequency-selective surface (OCFSS) becomes a programmable electromagnetic shield or pattern control device.

Patent 6,232,931; Navy case 76,915 (Serial 09/253,504) filed 19 February 1999; issued 15 May 2001.

CLAIMS ALLOWED; NOTICE OF ALLOWANCE

Frank E. Hanson
Peter M. Poirier

"Technique for Operating High-Energy Q-switched 0.9-µm Neodymium Lasers"

This invention describes a wavelength discriminating filter and procedure to efficiently operate a Q-switched neodymium laser on the 4F3/2 to 4I9/2 transition near 0.9 µm by suppressing the higher gain emissions near 1 µm. The invention applies in general to all neodymium-based lasers operating at 0.9 µm and, in particular, to neodymium-doped yttrium aluminum garnet (Nd:YAG) operating at 0.0946 µm.

Navy case 79,523 (Serial 09/252,610) filed 4 February 1999; Notice of Allowance 5 June 2001.

Steven J. Cowen — **"Method for Incorporating Total Internal Reflection into a Flexible Lithographic Mask"**

The novelty of the invention resides in the incorporation of critically angled surfaces to reflect unwanted optical energy out of the pattern mask. In the prior art, pattern masks that perform the frequency up-shifting function used energy-absorbing occluding layers to block unwanted light. However, such occluding layers had a tendency to accumulate heat energy that could damage the masks, and required low optical intensities to prevent mask damage. The invention allows the use of more intense optical irradiation of the pattern mask, thereby resulting in faster processing time.

Navy case 82,455 (Serial 09/605,036) filed 27 June 2000; Notice of Allowance 19 November 2001.

PATENT APPLICATIONS FILED

Stanislaw J. Szpak
Pamela A. Boss — **"Electrode and Method for Preparation of Electrode for Electrochemical Compression of Deuterium into a Metal Lattice"**

This invention provides an electrode and method for preparing the electrode that may be employed to electrochemically compress deuterium into a metal lattice of the electrode. An electrochemical cell is constructed that includes an electrolyte solution comprising a metallic salt and a supporting electrolyte. The metallic salt, when in a reduced state, absorbs deuterium. Both the electrolytic solution and supporting electrolyte are dissolved in heavy water. An anode and cathode are immersed and stable within the electrolytic solution. The anode is stable when polarized. A voltage is applied across the anode and cathode while a constant potential is maintained at the cathode. The constant potential is measured with respect to a reference electrode immersed within the electrolytic solution so that deposition of metallic ions occurs in the presence of evolving deuterium during electrolysis of the electrolytic solution. By this method, the cathode is transformed into the electrode.

Navy case 73,311 (Serial 07/632,896) filed 24 December 1990; pending.

Richard Scheps — **"Underwater Imaging Technique for the Detection of Shallow Submerged Objects"**

This high-resolution underwater imaging and ranging device scans an area underwater with a pulsed laser and records the reflected signal from the illuminated area with a gated photomultiplier.

Navy case 77,222 (Serial 08/908,778) filed 7 August 1997; pending.

Stephen D. Russell
Randy L. Shimabukuro
Yu Wang

"Transmissive Surface-Plasmon Light Valve"

The invention provides a light valve or optical modulating device that exploits color-selective absorption at a metal-dielectric interface by surface plasmons. The invention includes an electrode layer formed of an optically transparent substrate. A layer of electro-optic material is formed on the electrode. The electro-optic material has an index of refraction that may be modulated by an electrical bias. A second electrode is formed over the electro-optic material. Changes in a voltage bias across the electrodes modulate the index of refraction of the electro-optic material so that it selectively absorbs light (at different wavelengths) that passes through the light valve, depending on the index of refraction. The electrodes are made of a transparent or semitransparent material, such as indium tin oxide. Multiple light valves may be arranged in an array to form a flat-screen video display.

The novelty of the invention is that it provides a new mode of operation in that it is a transmissive device, rather than a reflective device.

Navy case 78,518 (Serial 09/172,581) filed 14 October 1998; pending.

Stephen D. Russell
Randy L. Shimabukuro
Yu Wang

"Microdynamic Optical Device"

This invention describes a light valve, display, optical modulating device or optical filter that uses a microdynamic construction to exploit the color-selective absorption at a metal-dielectric interface by surface plasmons. This invention has applications for displays in command and control, for multispectral imaging in surveillance and reconnaissance, and for filtering in optical communications and scientific instrumentation.

Navy case 78,968 (Serial 09/607,579) filed 29 June 2000; pending.

Richard Scheps

"Compact Solid-State Dye Laser"

This invention describes a compact solid-state dye laser that is diode-pumpable. The laser in its preferred embodiment consists of a monolithic state of materials including a solid-state l-μ-emitting laser gain element, a passive Q-switch, a second-harmonic doubling crystal, and the solid-state dye gain element.

Navy case 79,094 (Serial 09/539,460) filed 30 March 2000; pending.

Pamela A. Boss
Stephen H. Lieberman

"Spectroelectrochemical Device to Detect Airborne Contaminants"

The invention is a gas sensor that combines the sensitivity of electrochemistry with the specificity of spectroscopy for detecting organic contaminants in the gas phase. The sensing unit consists of a micro-electrode assembly comprising an inner working disk electrode and an outer auxiliary ring electrode. The inner working disk electrode is coated with a thiol coating. The micro-electrode portion of the sensor is used to continuously monitor the environment. When current flow between the two electrodes of the sensor occurs, a spectrum of the working electrode can be obtained to identify the electro-active species. The invention can operate in either a flowing stream or a quiescent environment. It can also be used to monitor for dangerous volatile organics, explosives, or drugs. The invention may also be used to perform surface-enhanced Raman spectroscopy (SERS).

An important novelty of the invention is that it incorporates micro-electrodes and SERS, which combine to have the capability of detecting organic contaminants in the ppm level. The micro electrodes can be arranged in arrays and require reduced capacitive charging currents. Micro-electrodes exhibit reduced signal-to-noise characteristics over standard-sized electrodes and can be configured into a variety of shapes.

Navy case 79,709 (Serial 09/461,533) filed 15 December 1999: pending. (Navy case 78,928 was merged with this case.)

David F. Schwartz
J. William Helton
Jeffery C. Allen

"Predictor for Optimal Broadband Matching"

A predictor for optimal broadband matching of the present invention comprises a computer program that inputs samples of load reflectance normalized to characteristic line impedance, the frequencies associated with the normalized reflectance samples, and a parameter specifying the number of frequency increments for calculation. The program calculates and outputs the highest power gain obtainable by any matching circuit and two associated system parameters: the power mismatch and the voltage standing-wave ratio.

Navy case 79,796 (Serial 09/540,438) filed 31 March 2000; pending.

Pamela A. Boss
Roger D. Boss
Stephen H. Lieberman

"Method of Preparing Durable Gold or Silver Film Substrates for Surface-Enhanced Raman Spectroscopy (SERS)"

This invention describes a process to prepare durable gold or silver films on substrates containing metal-oxide bonds for use in SERS. Steps in the process are (1) roughen the surface of the substrate, (2) react the roughened surface with a silanization agent such as (3-mercaptopropy) trimethoxy silane, (3) vacuum-deposit silver or gold onto the silanized surface, and (4) react with thiol coating. Depending upon the thiol coating used, these substrates can be used to detect VOCs, metal ions, and anions. Substrates prepared in this manner exhibit excellent adherence between the substrate surface and the metal film. The films can be immersed in water over extended periods of time. The silver or gold metal film can be used as the sensing layer of an optical waveguide device.

The substrates can be used by either the Navy or Marine Corps for environmental monitoring. The chemical modification of these substrates enables them to be used to detect and identify explosives, nerve agents, drugs, etc.

Navy case 79,987 (Serial 09/593,675) filed 14 June 2000; pending.

Richard Scheps

"Efficient Laser for High-Frequency Modulation"

A dye laser pumped by a laser diode allows highly efficient modulation into the 100-Ghz range for high bandwidth communications.

Navy case 80,110 (Serial 09/941,190) filed 28 August 2001; pending.

James Alsup

"Improved Comb-Spectrum Sensor"

A triplet-pair waveform for an active sonar is generated by an algorithm that provides good range resolution, high Doppler sensitivity, moderate bandwidth, and good power efficiency.

Navy case 82,302 (Serial 09/745,610) filed 22 December 2000; pending.

Pamela A. Boss
Stephen H. Lieberman
Leonard J. Martini
Leon Smith

"Fiber-Optic Sensor for Surface-Enhanced Raman Spectroscopy (SERS) to Detect Subsurface Contaminants"

The present invention comprises a fiber-optic probe fitted into a cone penetrometer module that draws a liquid sample from subsurface soil. The fiber-optic probe illuminates the sample and collects a Raman emission spectrum from the sample. The sample may then be purged from the module to allow another sample to be taken at a different soil depth.

Navy case 82,395 (Serial 09/805,665) filed 13 March 2001; pending.

Richard Waters
Monti E. Aklufi

“Micro-Electrical-Mechanical Systems (MEMS) Ultra-Sensitive Accelerometer”

The invention is a novel micro-electrical-mechanical system (MEMS) accelerometer that uses a light source for sensing acceleration.

Navy case 82,431 (Serial 09/808,570) filed 14 March 2001; pending.

Richard Waters
Monti E. Aklufi

“Novel Differential Circuit Utilizing Active Transistor-Like Optical MEMS Accelerometer”

This is a continuation in part of the above Navy case 82,431.

(Serial 09/886,293) filed 21 June 2001; pending.

Pamela A. Boss
Stephen H. Lieberman

“Hand-Held, Fiber-Optic Sensor for Either Normal Raman (NR) Spectroscopy of Surface-Enhanced Raman Spectroscopy (SERS)”

The invention is a hand-held, fiber-optic sensor used to detect and identify VOCs, inorganic anions, metal ions, etc., by either normal Raman spectroscopy or SERS. The sensor head consists of an optical window and a fiber-optic bundle. For SERS, the window is coated with a thin silver or gold film that is optically transparent. The metal film is then reacted with a thiol to form a self-assembled monolayer (SAM). The chemical nature of the coating determines its selectivity.

Navy case 82,433 (Serial 09/888,737) filed 25 June 2001; pending.

INVENTION DISCLOSURES AUTHORIZED

Ayax D. Ramirez
Stephen D. Russell
Randy L. Shimabukuro

“Resonance-Tunable Optical Filter”

This invention exploits color-sensitive absorption at a metal dielectric interface by surface plasmons. The invention provides a resonance-tunable optical filter that includes a dielectric and a metal layer through which electromagnetic radiation may be transmitted or reflected. A beam-steering apparatus is used to change the incident angle of the electromagnetic radiation whose optical properties are modified by choice of incident angle. The incident medium and exit medium are optically transmissive. Unlike the prior art, the invention device does not require spacers, alignment layers, and seals previously used to make liquid crystal filled surface-plasmon devices.

Navy case 79,095; authorized for preparation of patent application, 11 April 2000.

Richard Scheps **"Solid-State Lasers Pumped by Visible LEDs"**

An array of laser emitting devices (LEDs) emitting in the visible wavelength range is used to pump a solid-state laser rod that contains a transition element. The LEDs may operate continuous wave (CW) to generate a continuous laser emission, or they operate in pulsed mode to generate a pulsed laser emission. The LEDs may be coupled by an optical fiber to generate a pump beam along the fiber, or they may be focused. When pulsed, the LEDs generate much higher power for short periods of time, making possible high-output pulsed laser power. Exemplary lasers suitable for the present invention are Cr:LiSAF, which may be pumped in the red wavelengths, and Ti:$A1_2O_3$, which may be pumped in the green and blue wavelengths.

Navy case 82,321; authorized for preparation of patent application, 30 January 2001.

Stanislaw Szpak
Pamela A. Boss **"Power Conversion Unit"**

This invention describes a power-conversion unit consisting of a working electrode and counter electrode. Palladium and deuterium are co-deposited on the working electrode. During co-deposition, nuclear events of unknown origin occur resulting in enormous heat release. This heat can be used to provide power for a number of applications.

Navy case 82,379; authorized for preparation of patent application, 28 June 2000.

INVENTION DISCLOSURES SUBMITTED

Stephen D. Russell
Philip R. Kesten **"Interactive Display Device"**

This invention is a monolithically integrated display and sensor array that provides for interactive real-time changes to the display image.

Navy case 78,287; disclosure submitted 24 October 1996.

Stephen D. Russell
Randy L. Shimabukuro
Yu Wang **"Solid-State Light Valve and Tunable Filter"**

This invention describes an all solid-state light valve, optical modulating device or optical filter that uses color-selective absorption at a metal-dielectric interface by surface plasmons. The invention has applications for displays in command and control, for multispectral imaging in surveillance and reconnaissance, and for filtering in optical communications and scientific instrumentation.

Navy case 79,542; disclosure submitted 3 November 1997.

Stephen D. Russell **“Spatially Conformable Tunable Filter”**

The invention provides a flexible or pliable optical modulating device, light-valve or optical filter. It uses a sheet of polymer-dispersed liquid crystal (PDLC) material and specifically selected thin-metal electrodes on either side of the PDLC to form a capacitor structure. When a voltage is applied to the capacitor, the refractive index of the liquid crystal changes since it is an electro-optic material. The optical properties of one of the thin-metal electrodes are selected in combination with the PDLC to have a surface-plasmon resonance that is either narrow band or broadband depending on the application. The surface plasmon is then used to selectively absorb incident light at the metal-PDLC interface, while the remaining light gets reflected (or transmitted). By varying the applied voltage, and its corresponding change in PDLC refractive index, we can modulate the light valve or tune the filter.

The improvement over the prior art is that this can be configured conformably over a surface to improve the acceptance angle for the filter and to simplify the fabrication of the device as compared to conventional liquid crystals.

Navy case 79,545; disclosure submitted 1 June 1998.

James D. Warner **“Small-Boat Captive System”**
Thomas A. Knoebel
James R. Deuth

The small-boat capture device consists of two major components. The first component is a spring loop attached to the trailer and intersects the bow of the boat as it comes aboard the trailer. For the 10,000-lb small boat used in the initial application, a closing speed of 4.5 kn and a 1.5-inch-diameter nylon line provided the correct spring constant to provide a 2.5-g decelerate. The second component is a stainless-steel latching mechanism mounted to the bow of the small boat. The latch catches the line as it slides down the bow.

Navy case 79,950; disclosure submitted 22 January 1999.

Pamela A. Boss
Stephen H. Lieberman
Greg Theriault
Leonard J. Martini
Leon Smith

“Thermo-Electrically Cooled Sensor for Normal Raman (TE-NR) Spectoscopy or Surface-Enhanced Raman Spectroscopy (TE-SERS) to Detect Subsurface Contaminants”

The invention incorporates either a TE-NR or a TE-SERS sensor module inside a sampling, cone penetrometer probe. The inside of the probe is subdivided into three chambers—a lower sample chamber, a middle chamber housing either the TE-NR or TE-SERS sensor module, and an upper chamber housing the fiber optics. A water sample is taken into the lower chamber. It is then sparged with an inert gas to displace VOCs. VOC vapors are transported through a hydrophobic membrane and are concentrated onto a TE-cooled SERS substrate. The VOCs are identified and quantitated by either their Raman or SERS emissions.

Navy case 82,300; disclosure submitted 6 December 1999.

Stuart H. Rubin

"Hierarchical Phase Translation Menus for Object-Oriented Normalization in Data Mining"

A computer program assists in the capture of qualitative information, or phrases, in a classification system into a spreadsheet or database for data-mining application. The program presents the user with a series of pull-down menus to sort the data.

Navy case 82,394; disclosure submitted 21 March 2000.

Pamela A. Boss
Stephen H. Lieberman

"Device to Detect Anionic Nutrients by Surface-Enhanced Raman Spectroscopy (SERS)"

This invention is a sensor that uses cationic-coated SERS substrates to detect anionic nutrients *in-situ* and in real time. For the Navy, information on nutrient dynamics is used to understand chemical reactions that impact marine environmental quality and to predict the distribution, growth, and community structure of biota in the coastal ocean.

Navy case 82,434; disclosure submitted 19 January 2000.

Douglass C. Evans
Joseph D. Aboumrad
Earl E. Floren

"Blazed-Grating Optical Fiber Polarizing Coupler"

This invention develops a technique to selectively remove one polarization state of light propagating in a single-mode optical fiber more than the other polarization state over a large range of wavelengths. The light-carrying fiber is induced to radiate an accurately controllable percentage of its light by the introduction of a blazed Bragg grating into its core region for a few millimeters of length. The blaze, or tilt, of the periodic perturbation is selected to maximize polarization discrimination. The scattered light is incident on the outer surface of an identical fiber that is located in close proximity and in parallel to the first fiber. The identical grating in the second fiber scatters light radiated from the first fiber into its guided direction of propagation with maximum polarization discrimination.

Navy case 82,959; disclosure submitted 14 April 2000.

Ray H. Pettit

"A Maximum Likelihood Based Frequency Synchronizer for Dual-h, Full-Response 4-ary Continuous-Phase Modulation (CPM)"

Maximum likelihood (ML) techniques are useful in finding synchronizer structures for various cases. Synchronizers for frequency, phase, and timing have been found for various bandpass signaling techniques such as phase shift keying (PSK), differential phase shift keying (DPSK), quadrature amplitude modulation (QAM), minimum shift keying (MSK), and continuous phase modulation (CPM). These include data-aided, decision-directed, and clock-aided cases. For CPM, however, apparently only the single modulation index case has ML-based synchronizers. This invention provides a new nondata-aided, nondecision-directed MO-based frequency synchronizer (with no phase or timing information), derived for a full-response, dual-h (two modulation indexes), 4-ary CPM signaling scheme.

Navy case 82,969; disclosure submitted 27 June 2000.

Jon R. Losee
J. Charles Hicks
Everett W. Jacobs
Wayne C. McGinnis
Roger D. Boss

"Boron Nitride Solid-State Detector for Thermal Neutrons"

The invention is an electronic device, based on boron nitride films, that acts as a sensitive detector of thermal neutrons (neutrons with energies on the order of 0.025 eV). The device produces an electrical signal that varies with the neutron flux (number of neutrons per unit time crossing a unit area). The detector is useful for notifying an operator of the presence of nuclear material, which emits neutrons during the radioactive decay process.

Navy case 83,098; disclosure submitted 08 February 2001.

James Alsup
Harper Whitehouse

"A Sonar System Employing a Waveform and Processing Method That Provides High Doppler Sensitivity, Good Efficiency, and Improved Range Resolution"

The invention is a sonar system that includes a new comb-like waveform constructed by modulating the tines of a comb spectrum according to a set of Hermite functions defining a Hermite function space (HFS), and a processing method that reduces the sidelobes of the ambiguity function associated with the normally processed HFS comb waveform. Noise-limited performance remains high because the waveform is designed to be power-efficient: range ambiguity is superior to the highly rated sinusoidal frequency-modulation (SFM) waveform; and reverberation-limited performance is equal to, or better than, that offered by any other waveform designed for this purpose. The full Doppler sensitivity normally associated with pulsed continuous wave (CW) can be realized by the application to HFS signals of the constrained, regularized deconvolution method of this invention. The deconvolutionally processed Hermite-function comb waveform offers better reverberation-limited performance than does the triplet-pair comb waveform or any of its predecessors, while maintaining a noise-limited performance equal to the best of these.

Navy case 83,415; disclosure submitted 03 June 2001.

Pamela A. Boss

"Surface-Enhanced Raman Spectroscopy (SERS) Based Sensor Array for Chemical Detection"

The invention is a means of packaging surface-enhanced Raman spectroscopy (SERS) technology to detect environmental contaminants. The invention is a dosimeter badge comprised of an array of SERS elements in which each element is mounted on either a surface acoustic wave (SAW) device or thermocouple: Global Positioning System (GPS) unit, clock, processor/ controller, and power source. The SAW device or thermocouple senses a particular chemical reaction. Once a reaction has been detected, the processor accesses the GPS and clock to determine the time and place of the reaction, which then is recorded. The SERS elements are designed to react with a specific class of compounds.

The use of thiol-coated SERS substrates is an attractive technology for environmental modeling. These substrates can also be used to detect and identify chemical and biowarfare agents and explosives. Such a sensor could be used for surveillance.

Navy case 83,530; disclosure submitted 16 March 2001.

Stuart H. Rubin **"A Natural Language KASER"**

The KASER is predicated on a gradient descent search through the specializations followed by the generalizations and mixed transformations. KASER maximizes the potential for reuse through a declared object hierarchy. The question arises as to how we will provide for specialization as required by the knowledge amplifier (i.e., by Knowledge Amplification by Structured Expert Randomization [KASER]). Specializations are mapped to their generalizations. The system will learn to do this in a hierarchical fashion by following the methods prescribed for the KASER.

Navy case 83,590; disclosure submitted 25 June 2001.

Richard Waters **"Four Terminal Opto-Mechanical**
Monti E. Aklufi **Transistor for Sensing Applications"**

The invention describes the addition of a fourth electrode to the three-terminal MEMS USA accelerometer under development at SSC San Diego. The fourth electrode allows decoupling of the motion-sensing element (upper mirror) from the photo-sensing element (photodiode), adjustment of spring constant for the mirror support structure, independent adjustment of the initial spacing between upper and lower mirrors, and the ability to adjust the total force on the upper mirror without the feedback effects by using the potential on the photodiode.

Navy case 83,612; disclosure submitted 01 November 2001.

Stuart H. Rubin **"Knowledge Management for**
Command and Control Systems"

The Knowledge Amplification by Structured Expert Randomization (KASER) technology provides a methodology and implementation for learning more knowledge from that supplied through the use of declarative object trees. The new knowledge can be open or closed under deduction and can be incorrect. Whenever incorrect knowledge is corrected, supra-linear learning will occur given a symmetric domain. Today's expert compilers (e.g., the Layout Software Design System from Objects, Inc.) are brittle and cannot take advantage of a natural language (NL) bootstrap. The idea of building an expert compiler using a KASER, while conceptually simple, is difficult to realize.

SSC San Diego case 424; disclosure submitted 08 May 2001.

Pamela A. Boss
Gregory W. Anderson
Stephen H. Lieberman
John M. Andrews

"Thermoelectric-Cooled Surface-Enhanced Raman Spectroscopy (TEC-SERS) Sensor to Detect Volatile Organic Compounds (VOCS)"

The invention is a means of packaging surface-enhanced Raman spectroscopy (SERS) technology to detect environmental contaminants. The invention consists of a membrane interface probe (MIP), a Raman spectrometer system with a thermoelectric-cooled surface-enhanced Raman spectroscopy (TEC-SERS) module, a control module with telemetry, and a power module. The MIP is placed in a ground or monitoring well and is used to collect and transport any organic vapors that may be present to the TEC-SERS module. The vapors collect on the TEC-SERS substrate and are identified and quantified by their characteristic Raman emissions. The use of thiol-coated SERS substrates is an attractive technology for environmental modeling. These substrates can also be used to detect/identify chemical and biowarfare agents and explosives. Such a sensor could be used for surveillance.

The use of thiol-coated SERS substrates is an attractive technology for environmental modeling. These substrates can also be used to detect and identify chemical and biowarfare agents and explosives. Such a sensor could be used for surveillance.

SSC San Diego case 425; disclosure submitted 09 May 2001.

James Alsup
Harper Whitehouse
Shelby Sullivan

"A Sonar System Employing a Beamformer That Provides Improved Sidelobe Suppression for a Two-Dimensional Horizontal Array"

A sonar system (active or passive) using two-dimensional (horizontally planar) arrays with optimum or near-optimum sidelobe performance commensurate or superior to that which can be realized with a uniformly spaced one-dimensional horizontal line array.

SSC San Diego case 427; disclosure submitted 03 June 2001.

John M. Andrews
Stephen H. Lieberman
Li-Ming He

"A Neural-Network-Based Calibration Method for an Oil Content Monitor Using Multivariate Fluorescence and Optical Scattering"

The invention employs an artificial neural network to calibrate a monitoring system for on-line measurements of petroleum contaminants in water using a combination of ultraviolet fluorescent and light scattering.

SSC San Diego case 428; disclosure submitted 21 June 2001.

David W. J. Stein **"A Method of Detecting Anomalies in Multispectral and Hyperspectral Imagery Based on the Normal Compositional Model"**

The invention provides improved means of detecting anomalies in multispectral and hyperspectral imagery. Such detection is accomplished by applying the normal compositional model to the imagery and by using an anomaly-detection statistic derived from the model. The development of the model and the estimation of the parameters of the model are novel features.

SSC San Diego case 439; disclosure submitted 05 November 2001.

David W. J. Stein **"A Method of Detecting Targets Known up to a Simplex from Multispectral and Hyperspectral Imagery Based on the Normal Compositional Model"**

The invention provides improved means of using multispectral and hyperspectral imagery to detect targets with specified signatures. The signature model for a target need not be exact. The signature may be defined as an unknown convex combination of classes of the normal compositional model, where a class of the compositional model is a normally distributed random vector. The detection is accomplished by applying the normal compositional model to the imagery and computing a likelihood-ratio-detection statistic derived from the model. The development of the model, the estimation of the parameters of the model, and the detection statistic derived from the model are novel features.

SSC San Diego case 441; disclosure submitted 15 November 2001.

Aaron Judd **"Network Meaconing: Packet Modification to Disguise Operating System Identity"**

The invention is a process for removing or changing fields in the header of Transmission Control Protocol/Internet Protocol (TCP/IP) packets of a computer network system either at a firewall or router, thereby eliminating aspects of the packets that can be used to determine the operating system of the originating computer.

SSC San Diego case 444; disclosure submitted 13 December 2001.

PROJECT TABLES

SSC San Diego FY 01 ILIR Database

Project Title	Principal Investigator	SSC SD Code	Phone (619)55	DoD MA1	DoD MA2	FY 99 $(K)	FY 00 $(K)	FY 01 $(K)	FY 02 $(K) (Planned)	FY 03 $(K) (Planned)	FY 04 $(K) (Planned)	Keywords	Most Strongly Supported ONR/NRL Thrust	Next Most Strongly Supported ONR/NRL Thrust	ONR Sub-Element Supported
CRANOF: A Complexity-Reducing Algorithm for Near-Optimal Fusion with Direct Applications to Integration of Attribute and Kinematic Information	Dr. D. E. Bamber	24215	39219	CCC	INT	0	0	157	145	150	0	sensor fusion; complexity reduction; rule-based systems; uncertainty; probability logic; linguistic information; second-order probability; nonmonotonic reasoning	ID-5	ID-1	14/15
Acoustic Modeling in the Littoral Regime	P. A. Baxley	2857	35634	CCC	OSV	0	0	59	0	0	0	telesonar; underwater acoustic communications; channel model; beam tracing	US-1	IT-5	31/11
Detection of Ionic Nutrients in Aqueous Environments Using Surface-Enhanced Raman Spectroscopy (SERS)	Dr. P. A. Boss	2363	31603	MWT	MWT	79.8	89	59	0	0	0	sensors; surface-enhanced Raman spectroscopy	OE-6	MT-7	35/13
Automatic Matched-Field Tracking	Dr. H. P. Bucker	2857	33093	CCC	OSV	0	71	123	0	0	0	acoustics; acoustic detection and detectors	US-1	US-2	31/11
Information Fusion with Entropy and Conditionals (IFWEC)	Dr. P. Calabrese	27360	33680	CCC	INT	0	0	147	145	150	0	entropy; uncertainty; conditionals; events; propositions; logic; probability; complexity	OE-7	HP-2	14/15
Modeling of Acoustic Radiation in the Time-Domain with Applications to Non-Linear Structure-Acoustic Interaction Problems	Dr. S. Hobbs	2711	32018	OSV	ASW	0	0	98	0	0	0	acoustics; radiation; time-domain Kirchoff integral equation	US-6	US-7	12/14
High-Linearity Broadband Fiber-Optic Link Using Electroabsorption Modulators with a Novel Dual-Wavelength Second-Harmonic Cancellation Scheme	J. H. Hodiak	2825	39741	CCC	ELW	0	98	137	75	0	0	fiber optics; photonic link; electro-absorption (EA) modulator	PL-1	IR-3	21/22
Chaos Control and Nonlinear Dynamics in Antenna Arrays	Dr. V. In	2363	39287	CCC	AAW	0	0	294	285	300	0	chaos; nonlinear dynamics; stochastic	ID-2	ID-3	14/11
Neaconing: Network Meaconing for Improved Security	A. C. Judd	244207	34255	CCC	INT	0	0	113	145	150	0	network; fingerprint; hacker; security; adaptable intrusion scan	ID-1	IT-6	15/21

NOTES: MA = Mission Area; See Appendix for DoD Mission Area abbreviations, ONR Sub-Element Codes, and ONR/NRL Corporate Thrusts sorted by research area.

SSC San Diego FY 01 ILIR Database (contd)

Project Title	Principal Investigator	SSC SD Code	Phone (619)55	DoD MA1	DoD MA2	FY 99 $(K)	FY 00 $(K)	FY 01 $(K)	FY 02 $(K) (Planned)	FY 03 $(K) (Planned)	FY 04 $(K) (Planned)	Keywords	Most Strongly Supported ONR/NRL Thrust	Next Most Strongly Supported ONR/NRL Thrust	ONR Sub-Element Supported
Integration of Complex Information	D. S. Lange	244207	36534	CCC	INT	53.8	45	118	0	0	0	hypermedia; knowledge base; plan	HP-1	ID-2	15/14
Adaptive Distributed Object Architecture (ADOA)	W. J. Ray	2405	34150	CCC	INT	0	0	137	0	0	0	computer systems	IT-7	ID-3	15/52
Toward an Assessment of Flow-Induced Bioluminescent Signatures	Dr. J. R. Rohr	2363	31604	OSV	ASW	0	0	113	70	0	0	bioluminescence; flow visualization	US-6	SS-9	11/13
Knowledge Mining for Command and Control Systems	Dr. S. H. Rubin	27330	33554	CCC	INT	0	295	294	0	0	0	knowledge mining; mining tools	HP-1	HP-2	15/41
Advanced Hyperspectral Data Processing	Dr. D. W. Stein	2743	32533	OSV	ASW	75.6	125	118	0	0	0	hyperspectral data; data processing; stochastic; linear un-mixing; detection	ID-4	HP-2	14/52
Nucleic Acid Transfection Technology Development in Marine Mammals	Dr. B. H. Van Bonn	2351	31869	FSO	MIW	0	0	108	125	125	0	marine mammals; preventive medicine; nucleic acid; vaccines; plasmic	MT-4	MW-1	41/42
Micro-Electro-Mechanical Systems Ultra-Sensitive Accelerometer (MEMS USA)	Dr. R. L. Waters	2876	36404	MOB	MWT	0	0	147	275	300	0	MEMS; accelerometer; navigation; inertial; optical resonant cavity; Fabry-Perot; micro electronics	ED-2	ED-1	11/22
Robust Waveform Design for Tactical Communication Channels	Dr. J. R. Zeidler	28505	31581	CCC	INT	0	385	294	285	0	0	radio communications	IT-4	ID-6	21/11

NOTES: MA = Mission Area; See Appendix for DoD Mission Area abbreviations, ONR Sub-Element Codes, and ONR/NRL Corporate Thrusts sorted by research area.

SSC San Diego FY 02 ILIR Database

Project Title	Principal Investigator	SSC SD Code	Phone (619)55	DoD MA1	DoD MA2	FY 99 $(K)	FY 00 $(K)	FY 01 $(K)	FY 02 $(K) (Planned)	FY 03 $(K) (Planned)	FY 04 $(K) (Planned)	Keywords	Most Strongly Supported ONR/NRL Thrust	Next Most Strongly Supported ONR/NRL Thrust	ONR Sub-Element Supported
Coupled Mode Propagation in Elastic Media	Dr. A. T. Abawi	2857	33101	OSV	ASW	0	0	0	95	100	0	propagation; coupled modes; parabolic equations	US-1	US-3	31/11
CRANOF: A Complexity-Reducing Algorithm for Near-Optimal Fusion with Direct Applications to Integration of Attribute and Kinematic Information	Dr. D. E. Bamber	244215	39219	CCC	INT	0	0	157	145	150	0	sensor fusion; complexity reduction; rule-based systems; uncertainty; probability logic; linguistic information; second-order probability; nonmonotonic reasoning	ID-5	ID-1	14/15
On the Use of Optimal Signal Processing and Buried Seismometers to Detect Submarines in Littoral Waters	Dr. H. P. Bucker	2857	33093	ASW	OSV	0	0	0	145	150	150	seismometers; signal processing; surveillance; propagation models	US-1	US-2	31/32
Information Fusion with Entropy and Conditionals (IFWEC)	Dr. P. Calabrese	27360	33680	CCC	INT	0	0	147	145	150	0	entropy; uncertainty; conditionals; events; propositions; logic; probability; complexity	OE-7	HP-2	14/15
Coupled Inertial Navigation Sensors (CINS)	D. Fogliatti	2363	31626	CCC	ELW	0	0	0	115	150	0	MEMS; gyroscopes; inertial navigation	ED-1	IP-2	21/52
Automatic Geospatial Plan Execution Monitoring	Dr. M. J. Gherrity	244208	35322	CCC	SBS	0	0	0	95	125	0	geographical information; temporal information; plan execution	HP-1	HP-2	15/14
High-Linearity Broadband Fiber-Optic Link Using Electroabsorption Modulators with a Novel Dual-Wavelength Second-Harmonic Cancellation Scheme	J. H. Hodiak	2825	39741	CCC	ELW	0	98	137	75	0	0	fiber optics; photonic link; electro-absorption (EA) modulator	PL-1	IR-3	21/22
Chaos Control and Nonlinear Dynamics in Antenna Arrays	Dr. V. In	2363	39287	CCC	AAW	0	0	294	285	300	0	chaos; nonlinear dynamics; stochastic	ID-2	ID-3	14/11
Neaconing: Network Meaconing for Improved Security	A. C. Judd	244207	34255	CCC	INT	0	0	113	145	150	0	network; fingerprint; hacker; security; adaptable intrusion scan	ID-1	IT-6	15/21
Efficient Extremely Wideband Phased-Array Antenna	J. H. Meloling	2851	32134	CCC	ELW	0	0	0	125	150	0	phased array; wideband; electronic warfare; communications; information warfare; radar	IT-3	AP-4	11/21
Robust Tracking with a Neural Extended Kalman Filter	M. W. Owen	2725	32041	OSV	STW	0	0	0	145	150	0	tracking; Kalman filter; extended Kalman filter; neural networks	ST-1	US-1	14/41
Application of an Inverse Method for Analyzing Three Dimensional Shallow Water Underwater Sound Propagation	J. Riley	2857	35760	OSV	ASW	0	0	0	105	125	0	inverse methods; 3-D propagation; normal lmodes	US-1	US-2	31/11

NOTES: MA = Mission Area; See Appendix for DoD Mission Area abbreviations, ONR Sub-Element Codes, and ONR/NRL Corporate Thrusts sorted by research area.

SSC San Diego FY 02 ILIR Database (contd)

Project Title	Principal Investigator	SSC SD Code	Phone (619)55	DoD MA1	DoD MA2	FY 99 $(K)	FY 00 $(K)	FY 01 $(K)	FY 02 $(K) (Planned)	FY 03 $(K) (Planned)	FY 04 $(K) (Planned)	Keywords	Most Strongly Supported ONR/NRL Thrust	Next Most Strongly Supported ONR/NRL Thrust	ONR Sub-Element Supported
Toward an Assessment of Flow-Induced Bioluminescent Signatures	Dr. J. R. Rohr	2363	31604	OSV	ASW	0	0	113	70	0	0	bioluminescence; flow visualization	US-6	SS-9	11/13
Improved Receiver Synchronization for Continuous-Phase Modulation (CPM) Waveforms	B. E. Salisbury	2846	30879	CCC	FSO	0	0	0	145	150	0	continuous phase modulation; receiver synchronization; multi-h CPM waveforms	IT-3	CP-2	21/14
Nucleic Acid Transfection Technology Development in Marine Mammals	Dr. B. H. Van Bonn	2351	31869	FSO	MIW	0	0	108	125	125	0	marine mammals; preventive medicine; nucleic acid; vaccines; plasmic	MT-4	MW-1	41/42
Micro-Electro-Mechanical Systems Ultra-Sensitive Accelerometer (MEMS USA)	Dr. R. L. Waters	2876	36404	MOB	MWT	0	0	147	275	300	0	MEMS; accelerometer; navigation; inertial; optical resonant cavity; Fabry-Perot; micro electronics	ED-2	ED-1	11/22
Robust Waveform Design for Tactical Communication Channels	Dr. J. R. Zeidler	28505	31581	CCC	INT	0	385	294	285	0	0	radio communications	IT-4	ID-6	21/11

NOTES: MA = Mission Area; See Appendix for DoD Mission Area abbreviations, ONR Sub-Element Codes, and ONR/NRL Corporate Thrusts sorted by research area.

GLOSSARY

GLOSSARY

3-D	Three-Dimensional
3DGBQD	3-D Gaussian Beam/Quadrature Detector
ACM OOPSLA	Association for Computing Machinery: Object-Oriented Programming, Systems, Languages, and Applications
ADOA	Adaptive Distributed Object Architecture
ADW	Advanced Digital Waveform
AFCEA	Armed Forces Communications and Electronics Association
AI	Artificial Intelligence
ASW	Antisubmarine Warfare
*a*VLSI	Analog Very Large Scale Integration
BAM	Baseline Assessment Memorandum
BJT	Bipolar-Junction Transistors
BPSK	Binary Phase Shift Keying
BRAC	Base Realignment and Closure
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
C^4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CCK	Complementary Code Keying
CCSK	Cyclic Code Shift Keying
CDMA	Code Division Multiplexing
CDV	Canine Distemper Virus
CFAR	Constant False Alarm Rate
CMOS	Complementary Metal-Oxide Semiconductor
CRADA	Cooperative Research and Development Agreement
CRANOF	Complexity-Reducing Algorithm for Near-Optimal Fusion
CW	Constant Wavelength
DIA	Defense Intelligence Agency
DNA	Deoxyribonucleic Acid
DNF	Do Not Fragment
DoD	Department of Defense
DSP	Digital Signal Processor
EA	Electroabsorption
ELISA	Enzyme Linked Immunosorbent Assays
EMI	Electromagnetic Interference
EPI	Epitaxial

F	Fusion
FFT	Fast Fourier Transform
FRONT	Front-Resolving Observatory with Networked Telemetry
GBT	Geometric Beam Tracing
GPS	Global Positioning System
GRB	Gaussian Ray Bundles
GSM	General Stochastic Measure
H	Hemagluttinin
HSI	Hyperspectral Imagery
ICFF	Integrated Circuit Fabrication Facility
IEEE RSP	Institute of Electrical and Electronic Engineers: Rapid System Prototyping
IFSA	International Fuzzy Systems Association
IFWEC	Information Fusion with Entropy and Conditionals
ILIR	In-house Laboratory Independent Research
IMU	Inertial Measurements Units
IP	Internet Protocol
IR	Impulse Response
ISI	Intersymbol Interference
ISIPTA	International Symposium on Imprecise Probabilities and Their Applications
JTIDS	Joint Tactical Information Distribution System
KASER	Knowledge Amplifier by Structured Expert Randomization
LAN	Local Area Network
LPD	Low-Probability-of-Detection
M-QAM	M-ary Quadrature Amplitude Modulation
MEMS	Micro-Electro-Mechanical Systems
MFSK	M-ary Frequency Shift Keying
MFT	Matched-Field Tracking
MLS	Maximal Length Sequences
MMLS	Modified Maximal Length Sequences
MOS	M-ary Orthogonal Signaling
MOSFET	Metal-Oxide-Semiconductor Field Effect Transistor
MOSIS	Metal-Oxide-Semiconductor Implementation System
MSS	Military Sensing Symposium
MTBE	Methyl-Tertiary-Butyl Ether
MUPAD	Multi-Processing Algebra Data
NAFIPS	North American Fuzzy Information Processing Society
NATO	North American Treaty Organization
NAVFAC	Naval Facilities Command

NMAP	Network Data Management Protocol
NMMP	Navy Marine Mammal Program
NP	Nucleoprotein
NRSW	Navy Region Southwest
NSWC	Naval Surface Warfare Center
OCDM	Orthogonal Code Division Multiplex
OFDM	Orthogonal Frequency Division Multiplexing
OMFTS	Operational Maneuvers from the Sea
ONR	Office of Naval Research
OS	Operating System
PDF	Probability Distribution Function
PFD	Personal Flotation Device
PFF	Pixel Fill Fractions
PI	Principal Investigator
PIGA	Pendulous Integrated Gyroscopic Accelerometer
POC	Proof of Concept
PPM	Pulse Position Modulation
QD	Quadrature Detector
QPSK	Quadrature Phase Shift Keying
R&D	Research and Development
RDS	Remote Deployable Systems
Re	Reynolds (number)
RF	Radio Frequency
RFC	Request for Comments
RMI	Remote Method Invocation
RMS	Root Mean Square
RNA	Ribonucleic Acid
ROC	Receiver Operating Characteristic
RS	Random Sequences
SACLANT	Supreme Allied Commander Atlantic
SCAPS	Site Characterization and Analysis Penetrometer System
SCM	Stochastic Compositional Model
SERDP	Strategic Environmental Research and Development Program
SERS	Surface-Enhanced Raman Spectroscopy
SGB	Simple Gaussian Beams
SNR	Signal-to-Noise Ratio
SOPL	Second-Order Probability Logic
SYSCTL	System Controls
TCP/IP	Transmission Control Protocol/Internet Protocol
TE	Thermoelectric
TEC	Thermoelectric Cooler

UCSD	University of California, San Diego
USA	Ultra-Sensitive Accelerometer
UUV	Unmanned Undersea Vehicle
VLA	Vertical Line Array
VOC	Volatile Organic Compounds
WDM	Wavelength Division Multiplexing
WLAN	Wireless Local Area Network

APPENDIX: DATABASE DEFINITIONS

APPENDIX: DATABASE DEFINITIONS

ONR Sub-Element Codes

Codes	Topic	Codes	Topic
11	General Physics	24	Energy Conversion
12	Radiation Sciences	31	Ocean Sciences
13	Chemistry	32	Ocean Geophysics
14	Mathematics	33	Atmospheric Sciences
15	Computer Science	34	Astronomy and Astrophysics
21	Electronics	35	Environmental Science
22	Materials	41	Cognitive and Neural Sciences
23	Mechanics	42	Medical Science
		52	Multidisciplinary Support

DoD Mission Areas

Codes	Letter Code	Topic	Codes	Letter Code	Topic
1	AAW	Anti-Air Warfare	10	MIW	Mine Warfare/Mine Countermeas.
2	AMC	Amphibious Warfare	11	MOB	Mobility
3	ASU	Anti-Surface Ship Warfare	12	MWT	Multi-Warfare Technology
4	ASW	Anti-Submarine Warfare	13	OSV	Ocean Surveillance
5	CCC	Command, Control & Comm.	14	PMD	Personnel/Medical
6	ELW	Electronic Warfare	15	SBS	Sea-Based Strategic Warfare
7	FSO	Fleet Support Operations	16	SPW	Special Warfare
8	INT	Intelligence	17	STW	Strike Warfare
9	LOG	Logistics	18	TNG	Training

ONR/NRL S&T Corporate Thrusts Sorted by Research Area

Research Areas	Corporate Thrusts	**Designations**
Strike		**ST**
	Autonomous Real-Time Targeting	-1
	Land Attack and ASUW	-2
RF Technologies and Architectures		**RF**
	RF Sensors for Surface/Aerospace Surveillance	-1
	Advanced Multi-Function RF System (AMRFS)	-2
	Solid State Electronics	-3
	Vacuum Electronics	-4
Information Dominance		**ID**
	Defensive Information Warfare	-1
	Common Operational/Tactical Picture & Visualization	-2
	Networked Combat System and Operations	-3
	Image Processing, Analysis, & Exploitation	-4
	Multi-Sensor Fusion for Surface/Aerospace Surveillance	-5
	Extending the Littoral Battle Space	-6
Platform and Theater Defense		**PL**
	Electronic Combat Mission Support	-1
	Electronic Combat Threat Warning	-2
	Electronic Combat Self Protection	-3
	Radar Arrays	-4
	Network-Centric EW	-5
	Simulation/Visualization/Planning	-6
	Threat Detection/Classification/ID	-7
	Onboard Jammers	-8
	Offboard/Expendables	-9
	Survivability/Lethality	-10
	Air Dominance	-11
	Theater Air Missile Defense	-12
Undersea Warfare		**US**
	Shallow Water Signal Processing	-1
	Environmental Adaptive Sonar Technology	-2
	Shallow Water Active ASW	-3
	Undersea Warfare Effectiveness	-4
	Cooperative ASW	-5
	Wide Area ASW Surveillance	-6
	Battlegroup ASW Defense	-7
	Undersea Weaponry	-8
Mine Warfares		**MW**
	Mine Countermeasures	-1
	Organic Minehunting (Sensing/Processing)	-2
	Mine/Obstacle Neutralization	-3
	Mine Sweeping/Jamming	-4

	Advance Force Operations	-5
	Mining	-6
Sustainment		**SU**
	Maintenance Reduction Technology	-1
	Condition Based Maintenance	-2
	Strategic Systems Sustainment	-3
	Logistics	-4
Expeditionary Operations		**EO**
	Expeditionary Operations	-1
Operational Environments		**OE**
	Space/Airborne Sensor Development	-1
	Remote/Space Sensing Processes	-2
	Space/Airborne Sensor Exploitation and Demonstration	-3
	Environmental Processes	-4
	Ocean, atmosphere & Space Model Development	-5
	Environmental Sensors & Data	-6
	Data Assimilation and Information Exploitation	-7
	Validation Studies	-8
	Environmental Quality and Environmental Biology	-9
	Pattern Recognition	-10
	Environmental Effects	-11
Surface and Subsurface Platforms		**SS**
	High Power Solid State Macro Electronics	-1
	Littoral Support Craft	-2
	Electrically Reconfigurable Ship	-3
	Advanced Hull Forms	-4
	Hydromechanics	-5
	Hull Life Assurance	-6
	Automation to Reduce Manning	-7
	Advanced Electrical Power Systems	-8
	Reduced Signatures	-9
Air Platforms		**AP**
	Air Vehicles	-1
	Propulsion and Power	-2
	Integrated Avionics, Displays and Advanced Cockpit	-3
	Survivability and Signature Control	-4
	Autonomous Ops (Uninhabited Combat Air Vehicle)	-5
Space Platforms		**SP**
	Spacecraft Technology	-1
Ground Platforms		**GP**
	Ground Combat Vehicles Systems Technology	-1
Human Performance		**HP**
	Decision Support & Collaboration for Optimal Mission Planning and Execution	-1
	Decision Aids	-2
	Human Factors & Reduced Manning	-3

	Manpower, Personnel & Training	-4
Medical Technology & Biocentric Technology		**MT**
	Casualty Prevention	-1
	Fit & Healthy Force	-2
	Combat Casualty Care & Management	-3
	Marine Mammals	-4
	Biorobotics	-5
	Biosensors, Biomaterials, Bioprocesses	-6
	Chemical-Biological Defense	-7
Materials and Structures		**MS**
	Naval Materials	-1
	Functional Materials	-2
	Synthesis, Processes & Characterization	-3
	Prediction & Simulation	-4
Energetic Materials and Lethality		**EM**
	Energy Conversion	-1
Electronics (Materials & Devices)		**ED**
	Navigation and Timekeeping	-1
	Sensing, Diagnostics & Detectors	-2
	Nanoscience	-3
	Plasma Science and Technology	-4
Visible and IR		**IR**
	EO/IR Electronics	-1
	EO/IR Sensors for Surface/Aerospace Surveillance	-2
	Electro-Optics	-3
Information Technology & Operations		**IT**
	Dependable, Real-time High-Assurance Information Systems	-1
	Intelligent Software and Autonomous Systems	-2
	Maritime/Military Radio Communications	-3
	Dynamic Wireless Networks	-4
	Submarine Communications	-5
	Security	-6
	Computational Methods	-7
Industrial Programs		**IP**
	Modeling and Simulation for Design, Engineering and Acquisition	-1
	Metals Processing and Fabrication	-2
	Advanced Manufacturing Enterprise	-3
	Composite Processing and Fabrication	-4
	General Manufacturing Issues	-5
	Energetics Processing and Fabrication	-6
	Electronics Processing and Fabrication	-7
	Affordability Programs	-8
	Dual Use Program	-9
	Technology Transfer Program/IR&D	-10

Warfare Analysis and Experimentation		**WA**
	Assessments and Studies	-1
	Modeling and Simulation	-2
	Kainotyping, Fleet/Corps Battle Experiments	-3
Corporate Programs		**CP**
	Naval Science Assistance Program	-1
	In-House Laboratory Independent Research (ILIR)	-2
	Textual Data Mining	-3
	S&E Education and Career Development	-4
	SBIR/STTR Program	-5

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